U.S. Department of Transportation

Federal Aviation Administration

AMENDMENT II

TO

PRODUCT SPECIFICATION FAA-E-2751 FOR

MODE S ANTENNA GROUP, EN ROUTE ARRAY

JULY 17, 1989

NOTE: AMENDMENT I WAS INCORPORATED INTO THE BASIC SPECIFICATION WHEN IT WAS REPRINTED MAY 26, 1987. AMENDMENT II IS THE ONLY OTHER DOCUMENT UPDATING THIS SPECIFICATION, FAA-E-2751.

Attachment (2)

1.) Page 16, Para. 3.2.1.1, Last Paragraph: In both lines 3 and 4 delete "Sum, Difference and Omni ports" and substitute "Sum and Difference ports".

2.) Page 16, Para. 3.2.1.1, Last Paragraph, Last Line: Add tolerances to frequencies as follows: "1030 ± 3.5MHz and 1090 ± 5MHz".

3.) Page 19, Para. 3.2.1.1.2.1, Last Paragraph, Next to Last Line: Change "36dB" to "35dB".

4.) Page 19, Para. 3.2.1.1.2.2, Second Paragraph, Line 3: Change "with" to Within".

5.) Page 21, Para. 3.2.1.1.2.3, Top of Page, Line 3: After "6 dB" insert the following: "(for a 20 foot SLS backfill cable, 4 dB for a 50 foot SLS backfill cable)".

6.) Page 29, Para. 3.2.1.5.2: Delete this paragraph in its entirety and substitute the following:
"<u>3.2.1.5.2</u> <u>Slip ring assembly.</u> A slip ring assembly shall be provided as an integral part of the rotary joint. The slip ring assembly for the ARSR-1, ARSR-2, FPS series and BOS rotary joints shall have 16 each one-wire circuits, each circuit capable of handling 5.0 amps at 208 volts over the range of dc to 60 Hz. The ARSR-3 slip ring assembly shall have a total of 30 each one wire circuits: 14 circuits at 1.0 amp, 11 circuits at 5.0 amps (6 spare circuits) and 5 circuits at 15 amps; each of these 30 slip ring circuits shall have power handling capacity of 208 volts over a range of dc to 60 Hz. The slip ring assembly shall be reliable and easily adjustable with a useful life of at least 25,000 hours operation without adjustment for rotation speeds up to 17 rpm. The leakage resistenance between adjacent slip rings circuits shall be 100 megohms or greater. Terminal strips shall be provided to terminate both ends of the slip ring connections. The slip ring input and output connectors on each rotary joint (ARSR-1, ARSR-2, FPS series and BOS) shall be MS connectors (see 3.2.2.4.3). The ARSR-3 rotary joint shall utilize the same identical connector and connector pin designations as used on the original ARSR-3 rotary joint."

7.) Page 32, Para. 3.2.2.1.3, Lines 3 and 9: Delete "±10" and substitute "±4" in both lines.

8.) Page 33, Para. 3.2.2.4.2: Delete this paragraph in its entirety and substute the following:
"<u>3.2.2.4.2</u> <u>Waveguide pressure.</u> All rotary joint channels (radar and beacon) shall be designed to operate continuously at 15 psig pressurization at elevations up to 12,000 feet above sea level. In the ARSR-3 and FPS series rotary joints, pressurization of the coaxial channels shall be isolated from the pressurization of the waveguide channels. In the ARSR-1 and ARSR-2 rotary joints, the

same pressurization may be common to both the coaxial channels and the waveguide channels. The BOS rotary joint which only has coaxial channels shall also be pressurized. Input air fittings supporting these requirements shall be provided on the stationary portion of the rotary joints for connecting the pressure supply. These fittings shall be easily accessible when the rotary joints are completely installed. The input air shall be allowed to flow fron the stationary ports of the rotary joints through the rotating ports of these rotary joints. The rotary joints shall not lose more than 1 psig in 1 hour when pressurized to their maximum limits and rotated from 0.5 to 17 rpm. The coaxial connectors on the rotary joints shall be pressure tight so that pressure leakage of the rotary joints shall not occur if one or more pressurized/unpressurized coaxial cables are connected/ disconnected."

9.) Page 34, Para. 3.2.2.4.4, End of Paragraph: Add the following new sentence: "Data values for attenuation and phase matching of each individual cable (between the rotary joint and antenna) plus each adapter cable (between the Mode S Sensor transmission line and rotary joint) shall be provided with each cable."

10.) Page 40, Para. 3.3.2, Second Paragraph: Delete this paragraph in its entirety.

11.) Page 51, Para. 4.1.2.1.4:
- A.) End of First Paragraph: Add "Contractor at his expense and risk may elect not to perform this test, but submit it to the operational environmental radiation of the on-site radar, after installation. No failure would mean approval of test."
- B.) Delete the last two (2) paragraphs in their entirety.

12.) Page 52, Para. 4.1.2.1.5, First Sentence: Between "rotary joint" and "test" insert "(excluding transmission lines, Para. 3.2.2.4.4)".

13) Page 53, Para. 4.2.1.3, Line 2: After "rotary joint type" insert: "(excluding transmission lines, Para. 3.2.2.4.4)".

14.) Page 55, Para. 4.2.2.2, Second Line: After radiating elements, insert "(complete dipole column assemblies)".

15.) Page 58, para. 4.2.5.3, First Line: After "Each rotary joint" insert "(excluding transmission lines, Para. 3.2.2.4.4)".

FAA-E-2751

8 FEBRUARY 1985

DEPARTMENT OF TRANSPORTATION

FEDERAL AVIATION ADMINISTRATION

Product Specification

for

Mode S Antenna Group, En Route Array

TABLE OF CONTENTS

FIGURES and TABLES

1. SCOPE.

1.1 Scope. This specification establishes the performance, design, test, manufacture, and acceptance requirements for the Mode S Antennna Group, En Route Array.

This specification describes the services, material, equipment, and performance required to provide an en route array antenna group which is to be colocated with long range radar antennas at en route Mode S sites. The antenna group is intended for mounting on a variety of en route radar antennas protected by a radome. The antenna group provides a conventional directional pattern, sidelobe suppression (SLS) pattern, and a monopulse difference pattern. The patterns have sharp underside cutoffs to control ground lobing. The purpose of the monopulse pattern is to support single reply estimates of the azimuthal positions of transponders within the main lobe of the sum pattern. This specification also includes a multi-channel rotary joint and an azimuth encoder.

1.2 Classification. The Mode S en route array antenna group shall be of the following types, as specified.

1.2.1 Type I. This type shall consist of two directional en route array antennas each having monopulse capabilities and including provisions to provide sum, difference, and side lobe suppression patterns: all necessary rf plumbing, including nine rf path rotary joints for the FPS-20 derivative radars such as the FPS-66 and FPS-67 primary radars: the en route array antennas shall be mounted back-to-back on an FPS-20 derivative radar such that:

a) the front looking en route array antenna is attached to the structure that supports the primary radar feed horn:

b) the back looking en route array antenna is attached to the back of the structure that supports the primary reflector: and

c) the phase centers of both antennas shall be at approximately the same height above ground.

1.2.2 Type II. This type shall consist of two directional en route array antennas each having monopulse capabilities and including the hardware and software to provide sum, difference, and side lobe suppression patterns: all necessary rf plumbing including nine rf path rotary joints for the ARSR-1E and ARSR-2 radars. The en route array antennas shall be mounted back-to-back on an ARSR-IE or ARSR-2 radar such that:

2. APPLICABLE DOCUMENTS

2.1 Government documents. Delete text and substitute: "The following documents of the issue in effect, on the date of the issuance of the solicitation form a part of this specification to the extent specified herein. Specifications with revison letters shall use the listed revision."

2.1.1 Federal specifications.

None

2.1.2 FAA specifications.

FAA-D-2494/b	Technical Instruction Book Manuscripts: Electronic, Electrical and Mechanical equipment Requirements for Preparation of Manuscript and Production of Books
FAA-E-2716	Mode S Select Beacon System (Mode S) Sensor
FAA-G-1210d	Provisioning Technical Documentation
FAA-G-1375	Spare Parts-Peculiar for Electronic, Electrical, and Mechanical Equipment
FAA-G-2100c	Electronic Equipment, General Requirements

2.1.3 Military specifications.

MIL-C-3643	Connector, co-axial, Radio Frequency, Series N, Associated Fittings: General Specifications For
MIL-C-5541	Chemical Conversion Coatings on Aluminum and Aluminum Alloys
MIL-C-8514	Coating Compound, Metal Pretreatment, Resin Acid
MIL-C-39012	Connectors, Coaxial, Radio Frequency: General Specifications For
MIL-C-83286	Coating Urethane, Aliphatic Isocyanate, For Aerospace Applications
DOD-D-1000B	Drawing, Engineering and Associated Lists
MIL-E-17555	Electronic and Electrical Equipment Accessories and Repair Parts, Packaging and Packing of
MIL-P-13949	Plastic Sheet, Laminated, Metal Clad

2.1.7.1 DOT/FAA publications.

DOT Order 6365.1A	U.S. National Aviation Standard for the Mode Select Beacon System (Mode S)
DOT Order 1010.51A	Selection Order: U.S. National Aviation Standard for the Mark X (SIF) Air Traffic Control Radar Beacon System (ATCRBS) Characteristics
FAA Hdbk 6040.10	Equipment Failure Handbook

2.1.7.2 Military publications.

MIL-Hdbk-217	Reliability Prediction of Electronic Equipment
MIL-Hdbk-472	Maintainability Prediction
RADCTR-75-22	RADC Nonelectronic Reliability Notebook

2.2 Non-Government documents. The following documents form a part of this specification to the extent specified herein. Unless otherwise indicated herein the issue in effect on the date of the invitation for bids or request for proposal shall apply.

National Electrical Code by National Fire Protection Association

2.3 Availability of documents.

2.3.1 Federal documents. Information on obtaining copies of federal specifications and standards may be obtained from the General Services Administration Offices in Washington, D.C.: Auburn, Washington: San Francisco, California: Denver, Colorado: Kansas City, Missouri; Atlanta, Georgia; Chicago, Illinois: New York, New York; Boston, Massachusetts; New Orleans, Louisiana: Fort Worth, Texas; and Los Angeles, California.

2.3.2 FAA documents. Copies of the applicable FAA specifications and drawings and other publications whose sources are not identified in the following paragraphs may be obtained from the Federal Aviation Administration, 800 Independence Avenue, SW., Washington, D.C. 20591, Attention: Contracting Officer. Requests should fully identify the material desired: use specifiction numbers, dates, amendment numbers, and complete drawing numbers. The request should also identify the invitation for bids, request for proposals, or contract involved, or other use to be made of the requested material.

2.3.3 Military documents. Single copies of the military specifications, standards, and publications may be obtained from the Naval Publications and Form Center, 5801 Tabor Avenue, Philadelphia, Pennsylvania 19120. The RADC Nonelectronic antenna structures, with provisions for azimuth and elevation angle adjustment:

c. ~~substitute:~~ "Rotary joint interface kit including rf plumbing, coax cables and waveguides to interface the rotary joint with the respective primary radar and beacon antennas."

d. a rotary joint, including a housing, mounting hardware, 3 primary radar channels and 6 beacon channels with all associated hardware, a slip ring assembly, and dual azimuth encoders:

e. ~~substitute:~~ "Special tools, fixtures, and test equipment for depot maintenance of antenna and rotary joints."
~~and shimming it in the raised position:~~

f. all special tools, test and maintenance equipment for installing, testing and maintaining antennas, rotary joints, and encoders (Example: probe for checking power and phases of radiating dipoles):

g. documentation that includes instruction books, equipment test plans and reports, and reliability and maintainability test plans and reports: and

h. parts provisioning (common and peculiar).

Item a, f, g, and h above are applicable to all type classifications. All other items are unique to each primary radar type and/or facility.

3.1.1 Item diagrams. - A functional flow diagram of the specified equipment is shown by figure 3-1.

3.1.2 Interface definition. - The Mode S en route array antenna group, in the context of the overall Mode S system, also is shown by figure 3-1. The actual interfaces between the en route array antennas and the system are:

a. Physical interface - en route array antennas attached to primary radar structure: and

b. electronic/electrical interface - en route array antennas connected, through rotary joint to Mode S transmitters and receivers.

3.1.2.1 Physical interface. The physical interface between the en route array antennas and the primary radar is the mounting structure. The constraints on mounting location of the front looking chin mounted en route array antenna include the following:

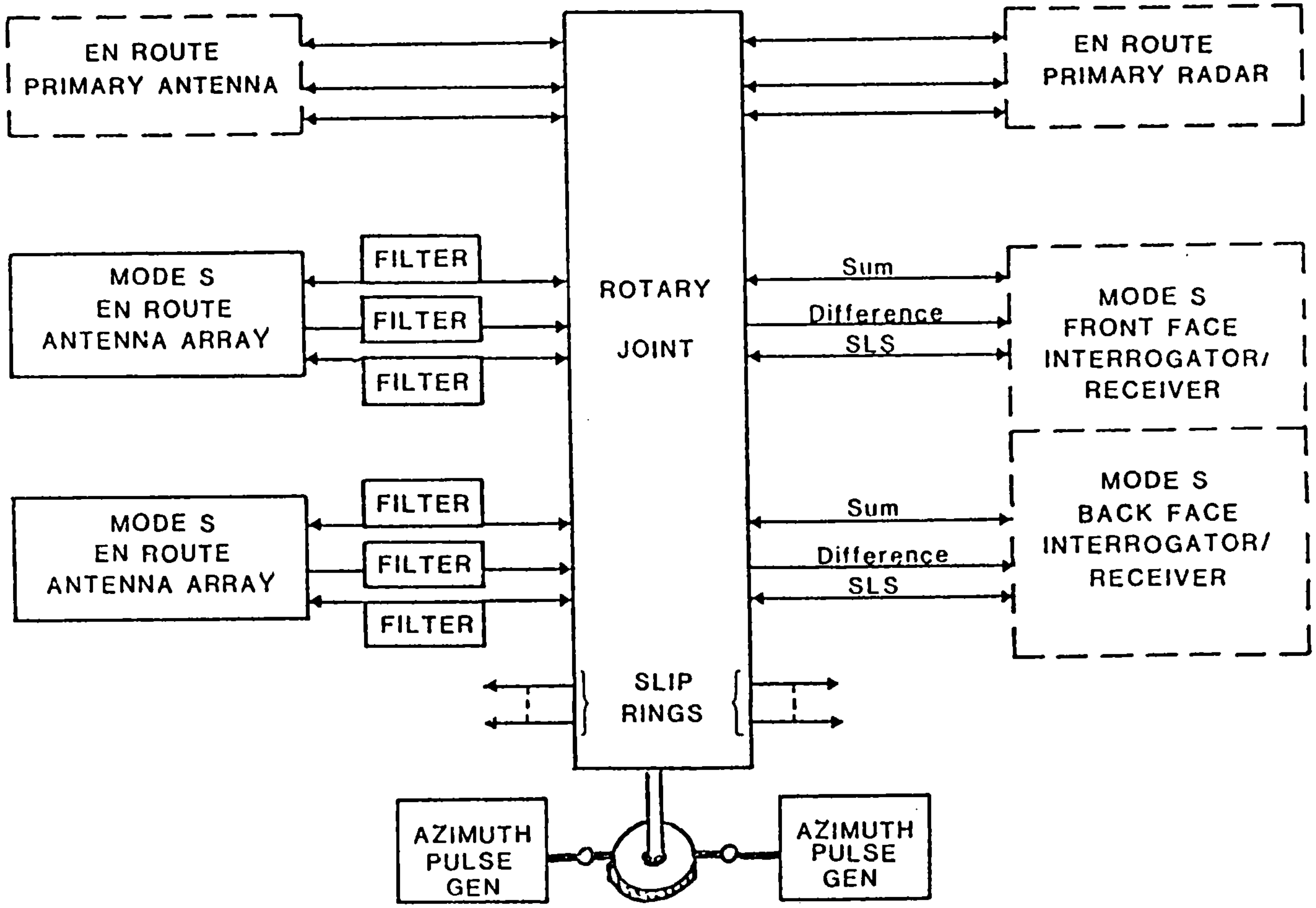

Figure 3-1: Mode S En Route Array Group - Functional Diagram

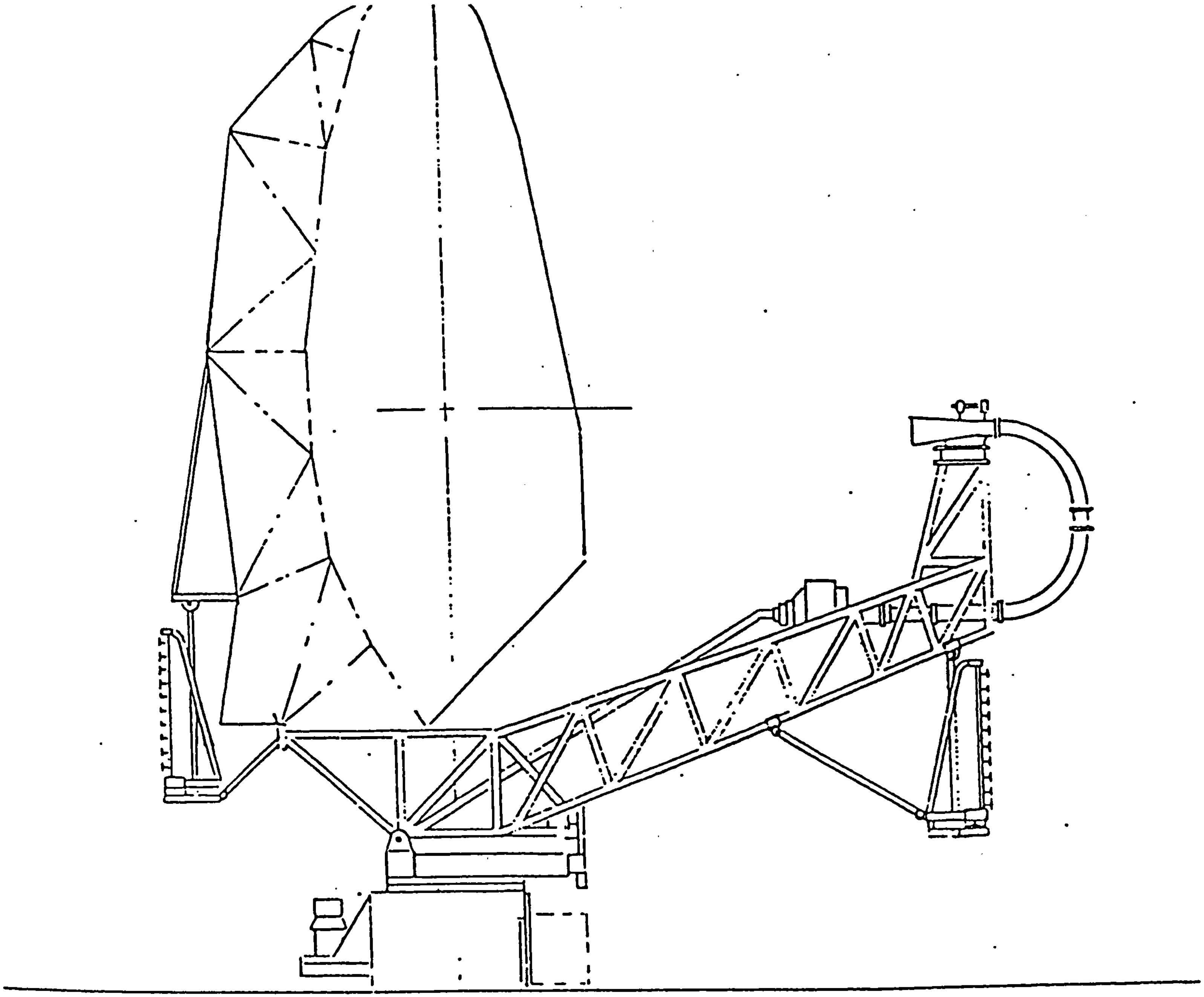

Figure 3-3: Mode S antenna chin mounted on ARSR-2 radar

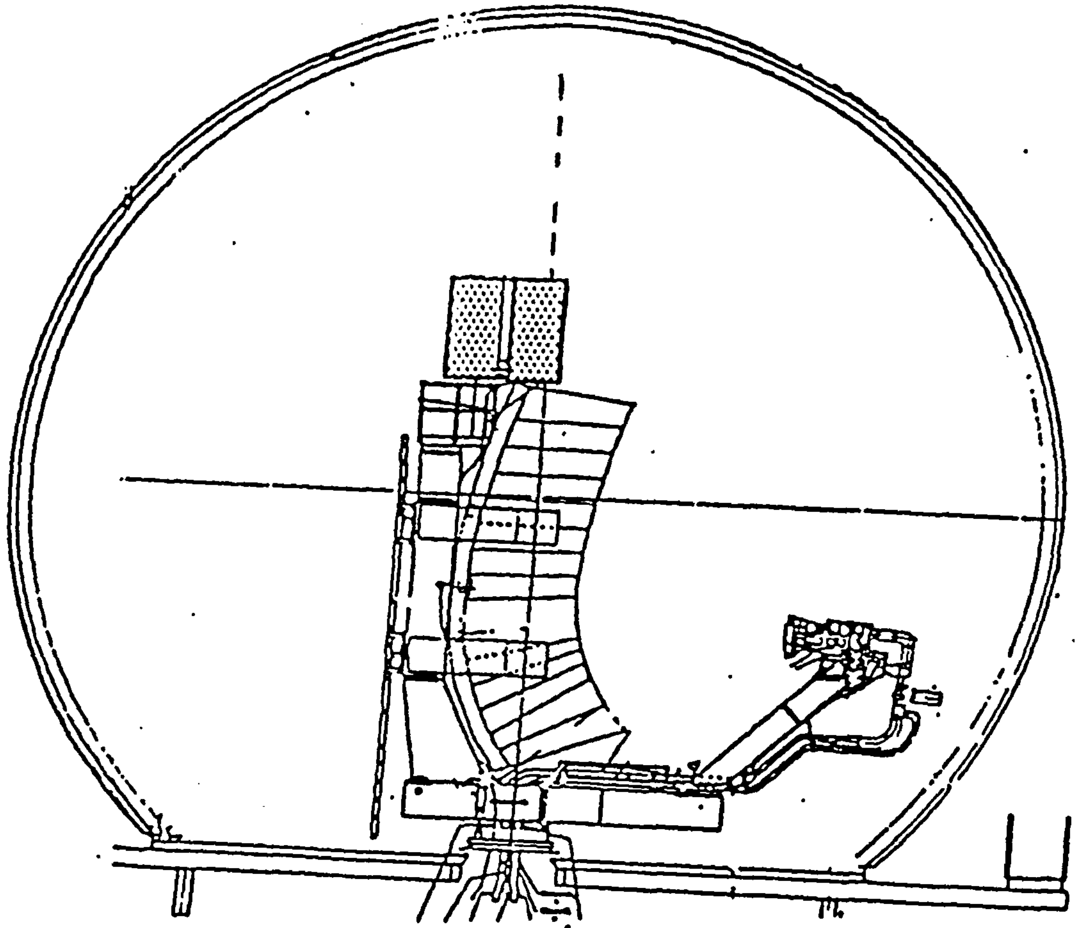

Figure 3-5: Mode S antenna top mounted on ARSR-3 radar.

b. Rotary joint assemblies - according to type
   (1). housing
   (2). ~~mounting hardware~~ Interface kit including mounting hardware.
   (3). three L-band paths for the primary radar, with associated waveguide ports, connectors, covers, and terminations except for beacon only system rotary joint (type III)
   (4) six L-band paths for en route array antenna pair, with associated connectors, caps, and terminations
   (5). slip ring assembly
   (6). two azimuth encoders (part of rotary joint)

c. Documentation
   (1). design data
   (2). progress reports
   (3). instruction books and instruction book manuscript
   (4). equipment test plans and reports
   (5). reliability and maintainability plans and reports
   (6). installation plan and reports
   (7). drawings

d. Test and maintenance equipment.
   (1) All special tools, fixtures, and test equipments required for field maintenance and replacement of the antenna, filter, rotary joint and azimuth pulse generator (APG).

   (2) Special tools, fixtures, and test equipments required for depot maintenance activities.

3.1.4 Government-furnished property list. ~~No Government Property will be provided for the design, manufacture, fabrication or test of the antenna group other than copies of available technical instruction books on the primary en route radars.~~ GFE will be provided as defined in the contract.

3.2 Characteristics. All characteristics described by this section of the specification shall be capable of being measured, and such measurements will be the basis for the inspections described by section 4 of the specification.

3.2.1 Performance requirements. The requirements described below shall be met under the service conditions of paragraph 3.2.5 with continuous unattended operation.

3.2.1.1 Pattern features. Each antenna directional array shall provide separate and independent sum, difference, and SLS ports (connectors). RF switching shall not be employed. The sum pattern shall have low azimuth sidelobe levels with a peak at or very near the principal elevation plane. The difference pattern shall have low azimuth sidelobes and shall have a null at zero degrees azimuth near the principal elevation plane. The SLS patterns shall cover all sidelobes and backlobes of the azimuth pattern.

NOTE 1: The intent of the above reference to "specified gain" is to specify the pattern for the real world application and requirements and not be slaved or subject to the produced or measured gain. If the final gain is n dB greater than specified, the requirements are still referenced to the specified gain.

3.2.1.1.1.2 Monopulse (difference) elevation pattern. The difference pattern, in azimuth, shall possess a null in the principal elevation plane so that there are two local pattern peaks, one on either side of and adjacent to the principal elevation plane. The antenna elevation pattern passing through both of these local difference pattern peaks at zero degrees elevation shall have the following characteristics when the antenna is mounted in its normal operational orientation. The shape of the relative field strength of the difference pattern shall be within ± 1 dB of the measured 1090 MHz sum principal elevation plane pattern over the range of elevation angles from 0 through +35 degrees and shall be within ±2 dB from -2 through +40 degrees elevation. The relative field strength shall decrease monotonically with decreasing elevation angle from 5 degrees to the point at which the pattern is 16 dB below the local peak (the -16 dB point). The slope of the pattern at any point between zero degrees elevation and the -16 dB point shall be no less than 1.8 dB per degree. The -16 dB point shall be above -4 degrees elevation. At all negative elevation angle below the -16 dB point and all positive elevation angles above +40 degrees elevation the field strength peaks shall not exceed 1 dB greater than those specified for the directional sum pattern (3.2.1.1.1.1).

3.2.1.1.1.3 SLS elevation pattern. At any azimuth angle for which the gain of the SLS pattern (at +6 degrees elevation) is within 6 dB of the peak of the SLS pattern at +6 degrees elevation, the SLS elevation pattern shall meet the following requirements when the antenna is mounted in its normal operational orientation. For azimuth angles within 10 degrees of the principal elevation plane (excluding the region between the crossover points), the relative field strength at 6 degrees elevation shall be between 0 and -2 dB. The relative field strength shall decrease monotonically with decreasing elevation angle between +6 degrees elevation and the underside -12 dB point at all applicable azimuth angles. The -12 dB point shall lie above -4 degrees elevation. From +6 through -2 degrees elevation, the shape of the SLS pattern shall be the same as that of the principal elevation plane sum pattern to within ±1.5 dB. The relative field strength at zero degrees elevation shall be -6 ±2.0 dB. The pattern slope at all elevation angles between zero degrees and the underside -12 dB point shall be at least 1.6 dB per degree for all azimuth angles.

The underside side lobes of the elevation pattern shall be at least 10 dB below the local peak of the pattern at all elevation angles below the underside -12 dB point.

At all elevation angles from -10 degrees through +70 degrees, the backlobe field strength shall be at least 35 dB below the global peak of the sum pattern.

3.2.1.1.2.2 Monopulse (difference) azimuth pattern. The difference pattern shall possess two peaks, one on either side of and immediately adjacent to the principal elevation plane. These pattern peaks are referred to as the difference pattern peaks in the requirements below. At any elevation angle, the higher of the two difference pattern peaks is the local peak of the difference pattern at the elevation angle.

At all elevation angles from -2 through +40 degrees, the following requirements shall be met. Each difference pattern peak shall occur within 2.5/cos y, (y=elevation angle) degrees of the principal elevation plane. The relative field strength of the weaker difference pattern peak to the local peak shall not be less than -1 dB. As the azimuth angle increases from the difference pattern peak at the negative azimuth angle, the relative field strength shall decrease monotonically to a null (the difference pattern null) and shall then increase monotonically to the difference pattern peak at the positive azimuth angle. The null depth shall be at least 28 dB below the local peak of the difference pattern at +6 degrees elevation and shall be at least 16 dB below the lower of the two difference pattern levels at the sum pattern cross-over points. On both sides of the principal elevation plane, with equal forward power applied at the sum and difference ports of the antenna, the field strength of the difference pattern shall cross over the field strength of the sum pattern at a point -3 dB ±0.5 dB below the peak of the sum pattern.

At all elevation angles from -2 degrees through +50 degrees, all sidelobe levels shall be at least 26 dB below the local peak of the difference pattern measured at the elevation angle corresponding to the global peak of the sum pattern.

At all elevation angles from -2 through +35 degrees, all sidelobes shall be at least 24 dB below the local peak of the difference pattern.

At all elevation angles from -10 though +70 degrees, the backlobe field strength shall be at least 35 dB below the highest peak of the difference pattern.

3.2.1.1.2.3 SLS azimuth pattern. The implementation of the SLS pattern shall include one radiating antenna which provides the major portion of the SLS energy for the hemisphere in the direction of the main interrogation and a separate radiating antenna which provides the major portion of SLS energy in the opposite hemisphere. With two directional arrays installed by 4 dB, then (a) the azimuth at which any such interval occurs shall be more than 60 degrees in azimuth from the principal elevation planes and (b) the SLS field strength shall exceed the sum pattern field strength.

From 0 through +20 degrees elevation the directional SLS pattern gain shall be within 10 dB of the local peak gain over an azimuth of ±68 degrees, excluding the region within the crossover points. Above +20 through +40 degrees elevation the directional SLS pattern gain shall be within 10 dB of the local peak gain over an azimuth of ±60 degrees, excluding the region within the crossover points.

The SLS pattern shall have the following characteristics over 1030 ±3.5 MHz as referenced to the sum pattern at the same frequency when equal forward power is applied at the sum and SLS connectors of the antenna. At all elevation angels between -2 and +30 degrees, the SLS pattern shall cross the sum pattern main lobe at two points, one on either side of the principal elevation plane. Each of these crossover points shall be between 15 and 21 dB below the local peak of the sum pattern. At all elevation angles above +30 and through +40 degrees the sum pattern crossover points shall both be between 12 and 21 dB below the local peak of the sum pattern. At any elevation angle from -2 through +5 degrees, the two sum pattern crossover points shall have field strengths which are the same to within 3 dB. At all elevation angles above +5 and through +40 degrees, the two sum pattern crossover points shall have the same field strengths to within 5 dB.

At all elevation angles from -2 through +40 degrees, the SLS field strength at all azimuth angles between the sum pattern crossover points shall not exceed the level of the lower of the two cross-over points. At all elevation angles from 0 through +30 degrees, the slope of the SLS pattern (in azimuth) at the crossover points shall be greater than 2 dB per degree. At all elevation angles from -2 degrees through +30 degrees, the SLS field strength on the principal elevation plane shall be at least 4 dB below the SLS field strength at the lower of the two crossover points at the same elevation angle.

At +25 degrees elevation, the phase of the sum output relative to the SLS output on the principal elevation plane shall be 0 degrees to within the tolerance specified below. This tolerance shall vary with the level of the SLS pattern on the principal elevation plane, as measured in dB below the lower of the two Sum/SLS crossovers, according to the following table:

applied (connected) simultaneously at two or more connectors. The antenna shall be capable of accepting the peak power and duty cycle requirements of the Mode S system as defined in FAA-E-2716.

3.2.1.1.6 Operating frequency. The antenna shall operate over the frequency range 1030 ±3.5 MHz and the frequency range 1090 ±5 MHz as specified herein.

3.2.1.1.7 Pattern squint and skew. The following requirements shall be met by the sum pattern over 1030 ±3.5 MHz and by both the sum and the difference patterns over 1090 ±5 MHz when the array is mounted in it normal operational orientation. Over all elevation angles from -1 through +10 degrees, the local peak of the sum pattern shall lie within 0.2 degrees of the principal elevation plane. Over all elevation angles above +10 through +40 and below -1 through -40 degrees, the local peak of the sum pattern shall lie within 0.3 degrees of the principal elevation plane. At zero degrees elevation, the null of the difference pattern shall lie within ±0.1 deg. of the principal elevation plane. From 0 through +35 degrees elevation, the variation in the position of the difference pattern null with respect to the principal elevation plane shall not exceed ± 0.01 x (elevation angle in deg.) deg. as measured at 5, 10, 15, 20, 25, 30, and 35 deg. elevation.

With the array antenna in its normally installed configuration on the en route radar antenna, the principal elevation plane of the array shall be aligned with the principal elevation plane of the primary radar antenna to within ±0.2 degrees in azimuth for all angles of array tilt.

3.2.1.1.8 Error pattern. The error pattern, as plotted from the antenna sum and difference signal characteristics over 1090 ±5 MHz, shall meet the following requirements.

At all elevation angles from -1 through +5 degrees, the magnitude of the slope of the error pattern at both positive and negative azimuth angles shall be within 5 percent of the slope of the error pattern for positive azimuth angles at zero degrees elevation. At all elevation angles from +5 through +20 degrees (+20 through +40 degrees), the magnitude of the slope of the error pattern at both positive and negative azimuth angles shall be within 10 (15) percent of the product of the slope of the error pattern for positive azimuth angles at zero degrees elevation and the cosine of the elevation angle. All antenna arrays shall have the same error pattern slope for positive azimuth angles at zero degrees elevation to within ±10% of a contractor specified nominal value.

pulse. Between the 90% amplitude points on the leading and trailing edges of the sum pattern output pulse, the shape of the difference pattern output pulse shall be the same as that of the sum pattern output pulse to within ±5% of the sum pattern output pulse.

3.2.1.3 Filter requirements. Each directional array antenna shall be supplied with three fixed tuned, low pass RF matched filters. One filter shall be placed at each of the output ports: sum, difference, and SLS. The purpose of each filter shall be to attenuate incoming RF energy (such as may be received from a colocated radar) a minimum of 50 dB over the range of 1200 to 11,000 MHz. The attenuation to transmitter RF energy throughout the range of 1026.5 to 1033.5 MHz shall not exceed 0.5 dB and the attenuation to received RF energy throughout the range of 1085 to 1095 MHz shall not exceed 1.0 dB.

3.2.1.3.1. Filter electrical requirements. The input VSWR of each filter over the frequency range from 1026.5 to 1033.5 MHz shall be less than 1.25:1 and over the frequency range from 1085 to 1095 MHz shall be less than 1.5:1. Each filter shall be capable of continuously transmitting, without breakdown, a peak power of 10,000 watts at a 1.0 percent duty cycle at any frequency between 1026.5 and 1033.5 MHz in addition to the power and duty cycle requirements specified in FAA-E-2716. Each filter shall be capable of withstanding the electromagnetic radiation environment of 3.2.5 and 3.3.2 when connected to either the sum port or difference port of the array antenna.

Each matched filter group shall meet the following requirements over the frequency range from 1085 to 1095 MHz. The phase shift through the filters shall be the same to within 10 degrees and the insertion losses shall be the same to within 0.2 dB. When a standard ATCRBS or Mode S reply (DOT Order 6365.1 and DOT Order 1010.51A) pulse with rise and fall times less than 55 nanoseconds is applied to any filter, the rise and fall times of the output pulse shall be less than 60 nanoseconds. In addition, the output pulses shall be flat to within -15% of the peak amplitude over the pulse duration (i.e., between the 90% amplitude points on the leading and trailing edges of the pulse). Between the 10% and 90% amplitude points on the leading and trailing edges of the output pulses of the matched filters, the pulse shapes shall be within ±10% of each other.

Between the 90% amplitude points on the leading and trailing edges of the output pulses, the pulse shapes shall be the same to within ±5% of each other.

A series N weatherproof male coaxial connector shall be provided at the antenna end of each filter and a series N weatherproof female coaxial connector shall be provided at the other end. These N types connectors shall be in accordance with MIL-C-3643.

f. Input voltage: The unit shall be degigned to operate with an input voltage of +15 VDC ±10% AT 300 mA maximum current.

The APG shall employ an optical encoder and solid state light source with a minimum lifetime of 100,000 hours. The above characteristics shall be met when measured at the end of a terminated cable consisting of a shielded twisted pair of 22 gauge wires for any cable length up to 300 feet.

3.2.1.5 Rotary joint. The rotary joint shall accommodate 9 channels, with channels 1 and 2 for high power primary, channel 3 for low power primary, and channels 4 thru 9 for Mode S. The required characteristics for these channels are shown by Table 3-1. Each rotary joint shall include two encoder drive shafts and provisions for mounting and driving both single and dual configurations of azimuth pulse generators and any other ancillary equipment.

output pulses shall be flat to within -15% of their respective peak amplitudes over the pulse duration of 50 microseconds (that is, between the 90% amplitude points on the leading and trailing edges). Between the 10% and 90% amplitude points on the leading and trailing edges of the output pulses, the pulse shapes in sections 4 through 6 and sections 7 through 9 shall be the same to within ±10% of the input pulse amplitude of the respective sections. Between the 90% amplitude points on the leading and trailing edges of the output pulses the two pulse shapes shall be the same to within ±5% of the input pulse amplitude of the respective sections.

3.2.1.5.1 Beacon Only System (BOS) rotary joint. The Type VII en route antenna group shall be provided with a rotary joint meeting the requirements of 3.2.1.5 and subparagraphs thereof except primary radar paths are not required. In addition, the BOS rotary joint shall be compatible with the Type FA-9344/2 BOS antenna pedestal. (This pedestal is a modified ASR-8 terminal radar pedestal: an ASR-8 rotary joint is physically compatible with the BOS antenna pedestal).

3.2.1.5.2 Slip ring assembly. A slip ring assembly shall be provided as an integral part of the rotary joint. The assembly shall contain a minimum of 14 one-wire circuits, each capable of handling 120 volts at 1 amp, 11 one-wire circuits, each capable of handling 120 volts at 5 amps and 5 one-wire circuits, each capable of handling 240 volts at 15 amps, all at a range from D.C. to 60 Hz. The assembly shall be reliable and easily adjustable with a useful slip ring brush life of at least 25,000 hours operation without adjustment for rotation speed up to 17 rpm. The leakage resistance between adjacent slip ring circuits shall be 100 megohms or greater. Terminal strips shall be provided to terminate both ends of the slip ring connections. The slip ring input and output connectors on the rotary joint shall be MS connectors. Connector pin/socket letters A through F and J through L shall be connected to the 5 ampere rings: N, P, and R shall be connected to the 15 ampere rings.

3.2.1.5.3 Phase shift tolerances. Adapter cables (3.2.2.4.1) for sections 4 through 9 of the rotary joint shall be phase matched to within 1.0 degree. The transmission paths between the sum and difference ports of each of the array antennas and the rotary joint shall be phase equalized so the differential phase shift between the two channels at 1090 ±5 MHz, shall be less than 3 degrees.

The total differential phase shift between paths through the adapter cables (3.2.2.4.1), the rotary joint (Table 3-1~~2~~) and the cables from the rotary joint to the antenna group (3.2.2.4.4) shall not exceed 5.0 degrees.

The en route radar antenna structure shall be balanced on its pedestal with the arrays installed. Each array group type shall include all required counterweights. The loads imposed on the radar antenna, under maximum operating conditions at 17 rpm, shall meet the following requirements. The minimum safety factors (based on stress levels) in the radar antenna structures shall be greater than 1.5. The pedestal peak and average drive requirements shall not exceed levels 60% above those required for rotating the radar antenna with a standard FA-7202 beacon antenna mounted on top of the reflector under the same environmental conditions. Under these same conditions the life of the en route radar pedestal bearings shall not be decreased more than 6%.

3.2.2.1.2 Structural requirements. - The structural design of the antenna arrays shall ensure undistorted radar/beacon operation rotational speeds up to 17 rpm. The safety factors (based on stress levels) under these conditions shall be a minimum of 2.0.

The deflections of the array when mounted in its worst case configuration, chin mounted, with rotational speeds from start-up to 17 rpm shall satisfy the requirements with respect to the nominal array structure contour defined by the Contractor when subjected to the conditions listed below. The deflections of the tips of the array measured in the horizontal plane (forward and back) shall be less than 3/4 inch, and the deflections in the horizontal plane at a distance midway between the vertical center line of the array and the tips of the array shall be less than 1/2 inch. The horizontal deflection of the array at any point on its vertical center line shall be less than 3/8 inch. The deflections of the tips of the array measured in the vertical plane shall be less than 3/4 inch. The elevation angles of the minus 6dB points on the underside of the sum radiation patterns on the respective elevation planes shall vary less than 0.5 degrees. The peak of the sum pattern shall deflect less than 0.1 degree in azimuth.

The conditions under which the above maximum allowable deflections apply include the following vibration components:

Axis	Displacement (inches)	Acceleration (g's)	Frequency (Hz)
Vertical (Up-Down)	0.10	0.1	3 to 100
Horiz. (Fr.-Back)	0.01	0.2	3 to 200
Trans. (Side-Side)	0.01	0.5	2 to 150

3.2.2.3.1 Anti-backlash gear. The gears that drive the azimuth pulse generators shall be anti-backlash gears and be designed to provide total compliance to the position accuracy requirements of Par. 3.2.1.4.

3.2.2.4 Rotary joint mechanical requirements. The rotary joint shall be compatible for mounting in the en route radar system pedestals without modification to either the pedestals or the rotary joint. Adapter kits shall be provided to interface the rotary joint to the various types of en route radar pedestals.

The rotary joint shall be contructed basically of aluminum alloy and shall be chemically treated to protect it against corrosion. Provisions shall be made to protect against electrolytic action taking place due to contact of dissimilar metals with the joint or at connection points within the RF systems. The rotary joint shall be weatherproof and dust tight. All RF energy handling surfaces shall not use finger stock or like material as a mechanical joint that is subject to movement or requires pressure to maintain contact during rotation. The finish shall be even and free of burrs, roughness, and undesirable marks and scratches on all interior and exterior surfaces.

The rotary joint shall be capable of rotating continuously in both the clockwise and the counterclockwise directions at speeds up to 17 rpm and shall not depend on radar antenna or pedestal components to maintain mechanical alignment.

3.2.2.4.1 RF section connectors. All connectors and waveguide ports on the rotary joint shall be the same as those currently employed on the radar rotary joints. Waveguide flanges for sections 1 and 2 shall be used for WR 650 waveguide. Section 3 shall have 7/8 inch coaxial EIA flanges. Sections 4 through 9 shall have Type N connectors. All bullets shall be captivated in the flanges. The waveguide flanges and coaxial connectors shall have weather seal covers for protection during transit, storage and handling. The positions of all connectors shall be compatible with existing installations in that it shall be possible to install the rotary joint and make all electrical connections satisfactorily without modifying existing cable or waveguide runs beyond the installation of cable/waveguide adapter components. All such cable/waveguide adapter components required for completely installing the rotary joint at any type radar shall be supplied with each rotary joint. The number of adapter components shall be held to the lowest possible.

3.2.2.4.2 Waveguide pressure. All rotary joint channels shall be capable of being pressurized. Sections 1 and 2 shall be designed to operate with 15 psia up to an elevation of 12,000 feet above sea level. The coaxial sections 3 through 9 shall be isolated from the pressure of waveguide sections 1 and 2, and

3.2.3 Reliability. The mean time between failures for the antenna and associated filters (as a system) shall be a minimum of 50,000 hours. The mean time between failures for the rotary joint (not including brush wear) shall be a minimum of 50,000 hours. Rotary joint brush life shall be a minimum of 25,000 hours. The mean time between failures for the azimuth pulse generator shall be a minimum of 30,000 hours.

3.2.3.1 Reliability apportionment. In accordance with MIL-STD-785, the contractor shall employ standard analytical engineering techniques to apportion (or allocate) the MTBF requirements for the antenna with filters and the rotary joint to MTBF requirements for the major assemblies and components that comprise the equipments. Antenna components and assemblies to which MTBF requirements are apportioned shall include, as appropriate, radiating elements, power dividers and feed networks, cables and connnectors, and protective dipole coverings (radomes). The reliability prediction activity of 3.2.3.2 shall establish that the reliability requirement apportioned to each component and assembly is satisfied when the material and construction techniques of the contractor's design are employed.

3.2.3.2 Reliability prediction. The contractor shall perform a reliability prediction in accordance with the design prediction procedure of MIL-STD-756. This prediction shall utilize the hardware breakdowns developed under 3.2.3.1 above. The prediction shall demonstrate that all of the reliabililty requirements apportioned to equipment assemblies and components will be achieved using the materials and construction techniques of the contractor's design. In addition, the reliability prediction shall demonstrate that the antenna with filters and the rotary joint will meet the reliability requirements of 3.2.3. The use of MIL-HDBK-217 is not mandatory (5.9.1 of MIL-STD-756).

3.2.3.3 Reliability data base. All reliability data employed in the predictions required by 3.2.3.2 shall be collected in a comprehensive reliability data base. A separate section of the reliability status reports shall be devoted to describing the reliability data base as it evolves. This description of the data shall include:

a. the name of each reliability variable,

b. the symbol used to represent each variable in reliability predictions,

c. the definitions of each variable to include units, The contractor shall perform a comprehensive maintainability program in accordance with MIL-STDs 470 and 471, and MIL-HDBK-472, for both the antenna with filters and the rotary joint with associated dual APG's.

3.2.4.1 Maintainability prediction. The contractor shall use Procedure IV of MIL-HDBK-472 to verify that the antennas satisfy the maintainability requirements of 3.2.4 of this specification over the service life of the equipment. Procedure IV shall be modified by the contractor, as required, to reflect the specific operational use, environment, and maintenance plan applicable to the antennas, filters, and rotary joints. In addition, the maintainability prediction data generated by the Contractor shall include, explicitly, the maintainability parameters specified in 3.2.4.2.

3.2.4.2 Maintainability data base. All reliability and maintainability data employed in maintainability analyses, maintenance concept/plan justification, and maintainability prediction shall be collected into a comprehensive maintainability data base. The description of the data base shall include:

a. The name of each relevant reliability and maintainability variable.

b. The symbol used to represent each variable in maintainability calculations.

c. The definition of each variable to include units.

d. The numerical value or range of values assigned to each variable.

e. The justification for each numerical value used.

Numerical values assigned shall be justified based upon verification simulations, documented experience with the same or related equipments and materials, and/or engineering judgement. Reliability predictions (3.2.4.1) shall be derived from the contractor's reliability data base.

3.2.5 Environmental conditions. The antenna group shall be designed and fabricated for continuous operation under the ambient conditions of Environment II (3.2.15 of FAA-G-2100c) modified as follows:

Elevation:	0 to 12,000 feet above sea level
Temperature:	-50 to +70 degrees C

3.3.1.4 Thread protection and engagement. Whenever practical, screws and bolts shall extend at least 1-1/2 threads beyond the nut or equivalent engaging part, and maximum extension shall not exceed 1-1/2 threads plus 1/8 inches for screws up to 1 inch in length and 1/4 inches plus 1 1/2 threads for screws over 1 inch in length. Thread engagement in tapped parts other than nuts shall be a minimum thread length equal to the diameter of the screw or bolt.

3.3.1.5 Locking and safety wiring of screw thread assemblies. All screw thread assemblies shall be properly secured and shall be capable of withstanding vibration under operational and non-operational conditions. All internal bolts, screws, and fasteners within the antenna, filter, rotary joint and APG shall be safety wired or fitted with lock nuts to preclude their loosening or disengaging during operation.

3.3.1.6 Connectors. All connectors in the antenna group specified herein shall have solder-on center contacts and all center contacts shall be soldered. All center contacts shall be captured within the connector body if such connectors are available for the series selected by the contractor. All connector bodies shall be stainless steel or nickel plated brass (i.e., corrosion resistant). Unless otherwise specified herein, all connectors shall be series TNC, N, or SMA and shall meet all requirements of MIL-C-39012 associated with connector materials, design and construction, environmental performance, electrical characteristics and workmanship. The connectors shall not be varnished.

The directional, monopulse, and SLS connectors on the directional array antennas shall be located in position so that: (a) the connectors are easily accessible for connecting and disconnecting cables and filters, and for taping, and (b) the connectors cannot be easily damaged during antenna handling and installation (e.g., by laying the array structures on their backs).

3.3.1.7 Screening Any portion of the array that is open to possible insect entry and nesting shall be provided with protective screening.

3.3.1.8 Electronic enclosures. All antenna feed networks and associated connectors and cable assemblies shall be housed in protective enclosures. The enclosures shall be capable of preventing damage to these equipments during installation and maintenance.

3.3.1.9 Sliding contacts. With the exception of the rotary joint slip rings, electrical components with sliding contacts shall not be employed in the construction of the antenna, filter, rotary joint, or APG.

3.3.1.10 Terminals. Terminals and terminal lugs shall be in accordance with Requirement 19, MIL-STD-454.

3.3.1.11 Bearings. Only rolling contact bearings shall be used. Bearings shall have a minimum life expectancy of 50,000 hours and shall be in accordance with MIL-STD-454, Requirement 6. Bearing used in the azimuth pulse generator, 3.2.2.3, shall be permanently lubricated sealed type of precision grade ABEC-5 or better. Selection of the bearing shall take into account the low speed operation, possible moisture contamination, and the operating environment of the unit.

3.3.1.12 Finishes. Surfaces shall be given a protective finish in accordance with 3.7.7 of FAA-G-2100. Except for the necessary masking of parts such as electrical connectors, all exterior surfaces shall be finished in the following manner:

a. Zinc chromate conversion coating per MIL-C-5541, Class 3, Method IIIB or zinc chromate wash primer per MIL-C-8514, thickness 0.0002 to 0.0003 inches (aluminum parts only).

b. Primer, epoxy polyamide per MIL-P-23377, Class 1, thickness 0.0006 to 0.0009 inches. (Optional for non-metallic parts).

c. Topcoat, urethane, aliphatic isocyanate per MIL-C-83286, color No. 12197, per FED-STD-595, thickness 0.0014 inches minimum.

The finish coat shall be aviation orange (color No. 12197) in accordance with Federal Standard 595. The Contractor shall ensure that the exterior finish selected does not interfere with the electrical performance of the antenna.

3.3.2 Electromagnetic interference. The en route array antenna and all other electrical components of the antenna group shall be designed and fabricated such that all components of the antenna group meet all specified performance requirements of this specification when subjected to, and when operating in, an L-band en route radar high power RF radiation environment. This requirement shall be met over the 1.2 to 1.35 GHz frequency range for RF pulse widths of 0.5 microseconds to 10 microseconds, peak power levels of 6.5 MW, average power levels of 10 KW and at the duty cycles typical of each type of radar listed under classification paragraph 1.2.

The antenna group shall be designed and fabricated to meet the electromagnetic interference control requirements as specified in 3.3.2.6 of specification FAA-G-2100. The antenna group shall conform to the Part 4 electromagnetic interference requirements for class A3 equipments as specified in MIL-STD-461. The specified Part 4 requirements are CE03,CE06, CE07, CS01, CS06, RE02, RS01, RS02 part 1b and RS03.

3.3.3 Identification and marking. All identification data and markings shall be provided in accordance with 3.9 of FAA-G-2100c.

3.3.4 Workmanship. Workmanship shall be in accordance with MIL-STD-454, Requirement 9.

3.3.5 Interchangeability. All components of this en route array antenna group shall be interchangeable as stated in the subsequent paragraphs.

3.3.5.1 Front-looking and back-looking antennas. The front-looking and back-looking en route array antennas of an antenna pair, having parts as described by section 3.1 (2) of this specification, shall be interchangeable, regardless of facility type classification.

3.3.5.2 Facility types. The en route array antennas, having parts as described by section 3.1 (a) of this specification, shall be interchangeable among facility types. However, the components described by sections 3.1 (b) thru 3.1 (g) of this specification are unique to facility type, and interchangeable only within designated facility type. Required differences, if any, of components within facility type should be clearly defined by the contractor.

3.3.6 Safety. Provisions for personnel safety shall be in accordance with MIL-STD-454, Requirement 1, and also with FAA-G-2100c. All horizontal members of the array structure and the support structure which will not support the full weight of personnel working on the antenna shall be stenciled "No STEP" using black letters at least on inch high.

3.3.7 Human engineering. The components' design must conform to a high degree of human engineering standards, and the applicable provisions of MIL-STD-1472 shall apply. This includes the ease and certainty of fault detection and isolation, and the ease of rapid and effective replacement of defective modules at the lowest replaceable unit level.

3.3.8 Configuration Management. A configuration management program shall be established in accordance with FAA-STD-021.

3.4 Documentation. The documents specified herein shall be provided and delivered as required by the contract.

3.4.1 Design data. The contractor shall supply design data reflecting his approach to meeting the requirements of this specification. The design data shall be supplied in sufficient detail to permit government review prior to fabrication of deliverable hardware.

3.4.1.1 Array error analysis data. The design submission shall include the results of the error analysis required in 3.2.1.1.9.

3.4.2 Progress reports. Progress reports shall be submitted as specified in the contract schedule. These reports shall include a concise statement of the work accomplished for the reporting period, and work schedule for the forthcoming period: a summary status of the detailed design and a list of tests of any deliverable item: a summary of any meetings between the contractor and others participating in the program: and special problem areas, including proposed solutions. An analysis of critical events and activities, such as critical path if PERT is used, shall be included. This type of report may be presented in letter form. The report shall include the title, type of report, contract number project number and release date.

3.4.3 Instruction books. Instruction books manuscript copy, and reproducible artwork shall be furnished in accordance with FAA-D-2494. The size of the instruction book (with covers closed and all fold-outs stowed) shall be 8.5 inches and 11 inches.

The maintenance and step-by-step installation instructions in the instruction book shall be sufficient to permit FAA technicians to install and to completely troubleshoot and repair the equipment. All special tools, fixtures, and test equipment required for installation and maintenance, but not supplied by the contractor under this specification, shall be listed and described in the instruction books.

The instruction books shall include copies of Level 3 installation and maintenance drawings in accordance with DOD-D-1000 B. These drawings shall include exploded view presentations of the physical relationships among various basic parts, subassemblies, and units that comprise each equipment.

Two complete instruction books shall be supplied. One instruction book shall fully document the rotary joint and the APG. The second instruction book shall fully document the antenna and associated filters. Each instruction book shall be supplied in two volumes. One volume (Volume II) shall contain all depot maintenance procedures to include troubleshooting instructions and supporting data as well as refurbishment instructions. The other volume (Volume I) of each instruction

book shall contain the remainder of the information required by FAA-D-2494. The number of copies of each volume of each instruction book shall be in accordance with the contract.

All instruction book materials shall be validated in accordance with FAA-D-2494. The contractor shall validate the installation instructions for the antenna with associated filters, the rotary joint, and the APG as follows:

(a) a comprehensive engineering review of the instructions shall be performed by contractor personnel, and

(b) the contractor shall simulate the installation of the equipment at the contractor's plant by physically placing each piece of hardware in a position representing its properly installed position and simulating the performance of every tool operation using the actual tool intended. The FAA will witness or monitor all validation activities.

The contractor shall supply draft manuscripts for review, revised draft manuscripts for approval, and copies of draft manuscripts for distribution in accordance with the contract. Draft manuscripts for review must include the complete text but may not have all the necessary illustrations. The revised draft manuscript for approval and copies of the draft manuscript for distribution must include legible copies of all illustrations along with the complete text.

3.4.4 Reliability program plan. The contractor shall prepare and submit for Government approval, a reliability program plan in accordance with MIL-STD-785 and this specification. This program plan shall include a detailed milestone chart showing the time interval over which each major reliabilty program activity will be performed.

3.4.4.1 Reliability status reports. Test data results shall be submitted as described in 4.2.3. All other reliability program activities described in 3.2.3 of this specification shall be reported in comprehensive reliability status reports. These reports shall be prepared in accordance with MIL-STD-785 and shall be submitted according to the contractor's reliability program plan. Up-to-date reliability status reports shall be submitted at least monthly from date of contract through completion of all program's activities. The first reliability program plan shall show submission dates and corresponding government reviews for reliability status reports on the milestone chart of program activities. Reliability status reports will be subject to Government review and approval.

3.4.5 Maintainability documentation.

3.4.5.1 Maintainability program plan. The contractor shall prepare and submit for approval, a maintainability program plan in accordance with MIL-STD-470. The description of the work to be performed on each program task shall include a concise description of the objective of each task. It shall be clear from the program task descriptions that the objectivees are met. The program plan shall include a milestone chart that clearly shows the time interval over which each task will be performed. The development of the maintainability data base and related models required to support analyses and predictions shall be one specific identifiable task in the program plan.

3.4.5.2 Detailed maintenance concept and plan. The contractor shall formulate a detailed maintenance concept and a detailed maintenance plan in accordance with MIL-STD-470. The detailed maintenance plan shall include a summary description of each maintenance task to be performed in the field, at the FAA depot, or at any other facility. Task descriptons shall encompass all maintenance activities to include performance checks, fault diagnosis, disassembly, part interchange, part refurbishment, reassembly, alignment, and checkout. The frequency with which each task is to be performed shall be stated along with a description of the location (field, FAA depot, etc.) at which the task is carried out. Support equipment, special tools and test equipments, skill levels, and number of people required for each task shall be described. The maintenance concept and detailed maintenance plan for the antenna, filters, and rotary joint shall be consistent with the useful service life requirement.

The format of the detail maintenance plan shall include both an overview of the maintenance activities required and self-contained descriptions of each maintenance task to include the information described above. All of the maintenance tasks, procedures, and related data described in the instruction books shall be obtained from this maintenance plan as developed by the contractor.

The detailed maintenance plan shall include a concise list of all special tools, fixtures, and test equipments required for field maintenance activities and a similar list for depot maintenance activities.

The contractor's maintenance concept and detailed maintenance plan shall be justified by supporting analyses. The analyses shall demonstrate that the maintenance procedures, tasks, and data prescribed in the instruction book are sufficient to assure that operational (installed) equipments are performing within the specifications described herein. Preventive maintenance tasks (to include field and depot refurbishment) scheduled shall be shown to agree with anticipated rates of component (e.g., bearing) degradation. That is, component failures which degrade performance, and can reasonably occur, shall be tabulated. The frequency of such failures shall be estimated based upon standad sources to the maximum extent possible. The sufficiency of prescribed performance checks will be established by showing how these checks determine whether or not any of the listed failures have occurred. The contractor shall demonstrate that the performance checks prescribed for the field are sufficient to detect all of the failures listed and that the frequencies prescribed for performance checks are consistent with anticipated failure rates.

The maintainability plan prescribed by the contractor shall adhere to the following guidelines:

a. It shall be possible to disassemble the antennas, filters, and rotary joints in the field.

b. Maintenance procedures prescribed should minimize, to the extent possible, the frequency with which personnel must gain access to the equipment.

c. The periodic field maintenance checks shall include the measurement of the electric field radiated by each individual radiating element of the antenna using a suitable shielded probe placed over the element.

d. Requirements for special test equipment and tools shall be minimized by utilizing equipments in the current FAA inventory to the maximum extent possible.

3.4.5.3 Maintainability status reports. All maintainability program activities described in 4.2.4 of this specification shall be reported in comprehensive maintainability status reports. These reports shall be prepared in accordance with MIL-STD-470 and shall be submitted according to the contractor's maintainability program plan. Up-to-date maintainability status reports shall be submitted at least every two months from date of contract through completion of all maintainability program activities. The first maintainability status report shall include the maintainability program plan. The maintainability program plan shall show the submission dates and corresponding government reviews for maintainability status reports on the milestone chart, and shall outline the contents of each report.

A separate section of the maintainability status reports shall be devoted to describing the maintainability data base as it evolves.

All maintainability status reports shall be subjected to government review and approval.

3.4.6 Test plans and reports.

3.4.6.1 Test plans. The contractor shall submit recommended test plans for review and approval by the government. The plan shall show how the tests demonstrate compliance with the specified requirement. The government will review, approve or direct necessary changes to the plan within 20 days after receipt. The contractor shall incorporate such directed changes and resubmit the final test plans prior to any related equipment testing. If, during a test, the test methods or parameters, as agreed to by the government, are found to be inadequately specified, they shall be amended and further approved by the government.

3.4.6.2 Test reports. Upon conducting any specified tests in accordance with the approved test plan, the contractor shall record the results for submission for government acceptance in accordance with the contract schedules.

3.4.6.2.1 Failure recording and reporting. Failures during all test programs specified herein shall be recorded and reported in accordance with FAA-HDBK-6040.10 "Equipment Failure Handbook". The failure reporting form specified in the handbook shall be modified to include reporting the following additional data:

a. time of day failure occurred

b. downtime reported to the nearest minute, and

c. time of restoration of equipment to full service.

Copies of all failure reports shall be made a part of the appropriate test reports.

3.4.7 Installation plan and report. The contractor shall provide an installation plan in report form to permit the FAA to prepare for system delivery and follow-on installation and checkout activities in accordance with the contract Schedule. As a minimum, the report shall contain the following general and typical information.

a. Information on equipment placement limitations, e.g., maximum distances between equipment comprising the system.

b. Detailed physical description of the equipment including physical size, weight, clearance factors, ventilation or air-conditioning requirements, cable entry and exit features, etc.

c. Cable and duct/overhead ladder requirements. This section shall include such items as information on subsystem cable interconnection requirements, system cable connections to signal junction box, and quantity of cables to be used, etc.

d. Power requirements. Information on size and type of power cabling to be used, compatible with type and size of government furnished power panels, and consistent with National Electric Code requirements, etc., shall be included.

e. System and equipment grounding requirements shall be stated consistent with FAA-STD-019 and FAA-STD-020.

f. Any other technical or general information that will be required in order to properly prepare a site for installation activities for proper installation, operation and maintenance of the equipment.

3.4.7.1 Installation report. The contractor shall, if required by the contract, update this installation plan to represent the "as built" record and the resultant installation report provided within 90 days after each installation.

3.4.8 Drawings. The contractor shall provide drawings in accordance with 3.15 of FAA-G-1210d.

3.4.8.1 Master pattern and plan view parts layout. The contractor shall provide master pattern and plan view parts layout for all equipment in accordance with 3.11 of FAA-G-1210d .

3.4.9 Item identification. The contractor shall provide item identification in accordance with 3.10 of FAA-G-1210d for specific items contained in the parts lists as requested and as required by the contract.

3.4.10 Requests for approval (RFA's). RFA's shall be submitted in accordance with 3.4.6 of FAA-G-2100c. Each RFA submitted for a non-standard part shall include a comprehensive description of the subject part to include drawings and definition of the materials, construction, and mounting to be employed. The contractor's experience with identical or similar parts shall be cited to include summaries of recent environmental test results where available. All FAA and military specifications applicable to the part, the materials in the part, the construction of the part and the testing of the part shall be listed and the contractor shall state which, if any, of these specifications shall be adhered to in fabricating the part. The contractor shall provide a concise summary of reasons for not adhering to applicable FAA and/or military specifications when such specifications are available.

3.4.11 Configuration management plan. A configuration management plan shall be submitted in accordance with 10.2 (b), Appendix I of FAA-STD-021.

3.5 Qualification. The qualification, being the performance validation of the en route array antenna group in specific configurations and applications, is discussed in section 4 of this specification.

4. QUALITY ASSURANCE PROVISIONS

4.1 General. The contractor shall provide and maintain a quality control program with FAA-STD-016. The inspections and tests specified herein to demonstrate compliance with the requirements of this specification shall be performed in accordance with the quality assurance provisions of paragraph 4 of FAA-G-2100c.

4.1.1 Responsibility for inspection. The responsibility for performing all specified tests/verifications rests with the contractor, utilizing his own facilities or any commercial laboratory acceptable to the government. The government reserves the right to witness or separately perform all tests specified or otherwise inspect any or all tests and inspections and to request additional tests.

4.1.2 Design qualification tests. The en route array antenna group, including one directional antenna, one group of matched antenna filters, and one rotary joint (including APG's), shall be subjected to design qualification tests in accordance with 4.3.2 of FAA-G-2100c. The electrical ratings of all components shall be verified by analysis. These rating verifications shall demonstrate that the electromagnetic radiation and power handling capacity requirements of this specification have been met.

4.1.2.1 Antenna electrical tests. All antenna electrical tests shall be performed on an approved test range in accordance with Appendix 1 and having the following characteristics:

a. The length of the test range shall be $2D^2$ / or greater. (D is the maximum dimension of the antenna and is the wavelength at which the antenna is being tested.)

b. The source antenna dimensions and alignment shall be such that the maximum amplitude taper will not exceed 0.25 dB over the test aperture and the taper shall be centered on the test aperture.

c. Under all test conditions, the ratio of co-polarized direct-to-reflected path signal levels that will be detected by the antenna shall be 35 dB or greater. This value shall be met when the source antenna is radiating either vertically or horizontally polarized energy.

d. Under all test conditions, the ratio of co-polarized to cross-polarized signal levels over the aperture of the antenna shall be 35 dB or greater. This value shall be met when the source antenna is radiating either vertically or horizontally polarized energy.

The contractor shall prepare and submit for government approval, a test range validation report which verifies that the above range requirements have been met for all ranges that will be employed for the antenna tests of 4.1.2.1.1 and 4.2.1. This validation of antenna test range capability shall be submitted to the government 90 days prior to the start of related testing activities.

The contractor shall submit, within 90 days after award of contract, a plan and schedule for providing the required range facilities.

4.1.2.1.1 Pattern tests. Antenna pattern tests shall consist of the following:

Test	Reference Paragraph
Sum elevation patterns	3.2.1.1.1.1
Difference elevation patterns	3.2.1.1.1.2
SLS elevation patterns and phase	3.2.1.1.1.3
Sum azimuth patterns	3.2.1.1.2.1
Difference azimuth patterns	3.2.1.1.2.2
Error azimuth patterns and post-hybrid phase	3.2.1.1.4
SLS azimuth patterns	3.2.1.1.2.3
Cross-polarization	3.2.1.1.3
Gain	3.2.1.1.1.1
Pulse distortion	3.2.1.5
Squint and skew	3.2.1.1.7

Over each frequency band (1030 ±3.5 MHz or 1090 ±5 MHz) at which pattern performance is specified, patterns shall be recorded at three frequencies corresponding to the two extremes and the midpoint of the frequency band. The sum and SLS elevation patterns are, therefore, to be recorded at six frequencies (1026.5, 1030, 1033.5, 1085, 1090, and 1095 MHz). All pattern cuts shall be over the full range of angles for which performance is specified herein except that elevation patterns shall be recorded over 320 degrees: from -70 degrees elevation in front through + 90 to -70 degrees elevation in back. Azimuth patterns shall generally be recorded in 5-degree steps of elevation from the lowest elevation angle at which pattern performance is specified to the highest. An azimuth cut at zero degrees elevation shall be included in every case. All azimuth patterns shall include both normal and cross-polarization measurements. The SLS elevation patterns shall be measured at five azimuth angles equally spaced over 360 degrees and shall be measured over 320 degrees along the vertical plane through the center of the aperture and the local peak of the SLS pattern at zero degrees elevation as well as along the principal elevation plane. Two sets of patterns described above shall be recorded with each pattern set including each of the patterns specified.

The first set of patterns shall be recorded with the array mounted on the contractor's range with a minimum of obstructions and/or reflecting surfaces in the vicinity of the antenna. This set of patterns shall demonstrate that all applicable requirements of this specification have been achieved. The second set of patterns shall be recorded with the antenna attached to a contractor-supplied aluminum structure that represents the entire top surface of a typical ARSR-3 sail and the bottom of an ARSR boom including mounting plates. The structures simulating these surfaces shall be mounted in positions that accurately represent the reflecting surfaces when the array antenna is installed in its typical operating positions at zero degree tilt. This second set of patterns is to be supplied for information purposes only and there are no performance requirements applicable to this set of patterns. In addition to the patterns specified above, the following SLS patterns shall be recorded at 1030 and 1090 MHz and delivered to the government. For each combination of front-to-back amplitude ratio (4 each) and phase shift (8 each), the contractor shall measure SLS elevation plane patterns over 320 degrees (from -70 through +90 degrees to -70 degrees in back) along the vertical plane through the center of the aperture and the local peak of the SLS pattern at zero degrees elevation as well as along the principal elevation plane. For each amplitude and phase combination, the contractor shall also measure 360 degree azimuth patterns at -2 degrees and in 10 degree steps from 0 to 75 degrees elevation. Each SLS pattern herein described for measurement shall be recorded with only the SLS port of the antenna driven (or recorded) simultaneously such that the resulting pattern represents the power density in free space with the SLS and sum ports simultaneously excited in phase at equal input power levels.

At 1090 MHz, the contractor shall measure and record the post-hybrid phase over 360 degrees in azimuth in 5-degree steps from 0 degrees to +70 degrees elevation.

<u>4.1.2.1.2.</u> <u>Other electrical tests</u>. The VSWR at the sum and SLS

connectors shall be measured at 1026.5, 1030, 1033.5, 1085, 1090, and 1095 MHz (3.2.1.1.4).

The power handling capability at each antenna connector, including the difference channel shall be verified by recording (photographing) forward and reflected 1030 MHz pulse waveforms at 200 watts peak and 10,000 watts peak at the minimum duty cycles specified in 3.2.1.1.5. Pulse rise times shall be less than 120 nanoseconds. VSWR measurements at the frequencies of 1026.5, 1030, and 1033.5 MHz shall be measured and recorded at 10,000 watts peak input power at the specified duty cycles in 3.2.1.1.5.

4.1.2.1.3 Qualification of mechanical design. The size and weight requirements of 3.2.2.1.1 shall be validated by direct measurement on a production antenna.

Comprehensive structural analyses of the array antenna as mounted on ARSR-2, ARSR-3, and FPS-20/60 radars shall be employed to verify that the following structural requirements and mechanical restrictions have been met:

. ARSR safety factor,	3.2.2.1.1
. ARSR bearing stress,	3.2.2.1.1
. pedestal drive requirement	3.2.2.1.1
. array safety factor	3.2.2.1.2
. Array deflections	3.2.2.1.2

These analyses shall include detailed load computations for the structural elements of the array antenna and the radar reflectors. Load computations for the maximum operating conditions shall be conducted and reported.

The deflection performance of the array antenna shall also be validated against the requirements of 3.2.2.1.2 by means of a static load test of a production array structure with its associated support structure. This test shall apply loads representative of maximum array deflections under the most severe operating conditions as established by the contractor's analysis and verified by vibration test data. This static load test shall demonstrate that the array returns to its original contour (to within the contractor's flatness tolerances) when the load is removed. In addition to the structural analysis and testing required above, the contractor shall provide comprehensive analyses of the static and dynamic mechanical loads on and deflections of any exposed electrical components such as reflecting elements or screens and radiating elements.

All analyses and test data required to qualify the mechanical design of the antenna shall be reported in a single comprehensive test report.

4.1.2.1.4 Electromagnetic interference. The en route array antenna group shall be subjected to testing to verify that the requirements of 3.3.2 are met.

The MIL-STD-461 requirements shall be verified by using MIL-STD-462 test procedures.

All other 3.3.2 requirements shall be verified by using contrctor developed test procedures.

4.2 Quality Conformance Inspections

4.2.1 Type tests. The antenna, filters and rotary joint (including APG's) will be type tested as specified below in accordance with paragraph 4.3.4 of FAA-G-2100c.

4.2.1.1 Antenna tests. The following electrical tests shall be performed on each antenna type tested:

Test	Reference Paragraph
Sum elevation patterns	3.2.1.1.1.1
Difference elevation patterns	3.2.1.1.1.2
SLS elevation patterns and phase	3.2.1.1.1.3
Sum azimuth patterns	3.2.1.1.2.1
Difference azimuth patterns	3.2.1.1.2.2
Error azimuth patterns and post-hybrid phase	3.2.1.1.4
SLS azimuth patterns	3.2.1.1.2.3
Cross-polarization	3.2.1.1.3
Gain	3.2.1.1.1.1
Pulse distortion	3.2.1.5
Squint and skew	3.2.1.1.7

All sum and SLS patterns shall be measured at 1030 and 1090 MHz. Difference patterns shall be measured at 1090 MHz only. All pattern cuts shall be over the full range of angles for which performance is specified herein except that elevation patterns shall be recorded over 320 degrees as specified in 4.1.2.1. Azimuth patterns shall generally be recorded in 5 degree steps of elevation from the lowest elevation angle at which pattern performance is specified to the highest; an azimuth pattern shall include both normal and cross polarization measurements. The SLS elevation patterns shall be measured at five azimuth angles equally spaced over 360 degrees and shall be measured over 360 degrees along the vertical plane through the center of aperture and the local peak of the SLS pattern at zero degrees elevation as well as along the principal elevation plane. For all the pattern tests performed under this paragraph, the contractor-fabricated structure attached to the antenna for the tests of 4.1.2.1.1 shall not be mounted on the antenna. In additicn to the pattern tests specified above, the VSWR and power capacity measurements of 3.2.1.1.4 and 3.2.1.1.5 shall be included in the type tests.

4.2.1.2 Filter tests. Filters shall be type tested in matched groups of three. Each matched group of antenna filters tested shall be subjected to the following electrical tests under the environmental conditions specified below:

Test	Reference paragraph
Pass-band attenuation	3.2.1.3
Stop-band attenuation	3.2.1.3
VSWR	3.2.1.3.1
Power capacity	3.2.1.3.1
Phase shift (tracking)	3.2.1.3.1
Insertion loss (tracking)	3.2.1.3
Pulse shape	3.2.1.3.1
Pulse shape tracking	3.2.1.3.1

The power capacity measurements shall include the high-power VSWR measurements. The environmental conditions for the filter type tests shall be in accordance with 4.11 of FAA-G-2100c, modified as follows:

a. In Step 3 the temperature shall be held at the minimum for a time interval sufficient to ensure that the entire filter has cooled to at least -50°C prior to making measurements.

b. Delete Step 8 - one complete set of test measurements shall be made at the conclusion of Step 7.

The temperature limits for type testing are -50°C and +70°C. The high humidity value is 100% (-5%, +0%).

4.2.1.3 Rotary joint tests. The following electrical tests shall be performed on each rotary joint type with APG's installed:

Test	Reference paragraph
Isolation	3.2.1.5
Peak power (unpressurized)	3.2.1.5
Duty cycle	3.2.1.5
VSWR	3.2.1.5.2
Insertion loss	3.2.1.5.2
Phase shift change	3.2.1.5
Pulse shape (Channels 4,5,&6/7,8&9)	3.2.1.5
Phase and amplitude tracking (Channels 4&5, 4&6,7&8,7&9)	3.2.1.5
Pulse shape tracking (Channels 4&6, 7&9)	3.2.1.5
Frequency	3.2.1.5
APG Output and Jitter	3.2.1.4

The environmental conditions for the rotary joint type tests shall be in accordance with 4.11 of FAA-G-2100c, modified as follows:

a. In Step 3, the temperature shall be held at the minimum for a time interval sufficient to ensure that the entire rotary joint has cooled to at least -50°C prior to making measurements.

b. Delete Step 8 - one complete set of test measurements shall be made at the conclusion of Step 7.

The temperature limits for type testing are -50°C and +70°C. The high humidity value is 100% (-5%, +0%).

The type test shall be in three segments. Segment I shall make all measurements tabulated above at room temperature at three angles of joint rotation evenly distributed over 360 degrees. Segment II shall make all measurements tabulated above over the environmental scenario of 4.11 of FAA-G-2100c, (as modified above) with the joint rotating at 17 rpm in the chamber. Segment III shall make low power phase and amplitude tracking and pulse shape tracking measurements with the rotary joint continuously rotating at 17 rpm and subjected to the environmental scenario. If the contractor so elects, Segments II and III may be combined into a single segment.

4.2.2 Environmental tests. The contractor shall environmentally test the en route antenna group equipment in accordance with the environmental conditions specified in 3.2.5.

4.2.2.1 Environmental test of antenna electronics. The contractor shall environmentally test one fully assembled antenna less enclosure covers. The enclosure covers are to be removed in order to expose the antenna feed networks to the temperature and humidity conditions of the test chamber. Radiating elements may be removed in order to facilitate the measurement of element excitation voltages.

The antenna shall be placed in a chamber meeting the requirements of 4.11 of FAA-G-2100c, and subjected to the environmental scenario tabulated therein except that Step 8 shall be deleted and all required measurements shall be taken and recorded after the temperature of the antenna returns to nominal following Step 7. The temperature extremes shall be -50 degrees and +70 degrees Centigrade and the high humidity shall be 100% (-5%, +0%).

At each point in the environmental scenario at which test measurements are to be made, the phase and amplitude of the excitation at 100 radiating elements selected by the FAA shall be measured and recorded. Each measurement shall lie within the range about its nominal value prescribed by the contractor's allcwable variation for that output. The excitation levels at the radiating elements shall be measured as specified above with the sum, difference, and SLS ports separately driven at power levels below 10 dBm.

At the extremes of temperature, the allowable variations in excitation level shall not exceed ±2.0 dB rms and ±6.0 dB maximum relative to the nominal and the allowable variation in excitation phase shall not exceed ±15 degrees rms and ±40 degrees maximum relative to the nominal. At room temperature, the allowable variations in excitation amplitude and phase shall be less than ±15 dB rms/±4.0 dB maximum and ±10 degrees rms/±30 degrees maximum respectively. The nominal excitation levels and phases can be made a function of temperature only to the extent that all normal levels and/or nominal phases change by the same amount for the antenna input in question and only to the extent that the gain and relative amplitude and phase requirements of 3.2.1.1 are met.

<u>4.2.2.2</u> <u>Environmental test of antenna radiating elements</u>. The Contractor shall environmentally test 25 radiating elements of each type employed using a chamber and scenario satisfying the requirements of 4.2.2.1 above. At each point in the environmental scenario at which test measurements are to be made, the VSWR of each element shall be measured and recorded. Each measurement shall lie within the range assumed in validating antenna performance with the statistical analysis of 3.2.1.1.87. At extremes of temperature, all element VSWR's shall be less than 2.0:1 referenced to the nominal element impedance. At room temperature, all element VSWR's shall be less than 1.5:1.

<u>4.2.3</u> <u>Reliability demonstration</u>. The contractor shall perform reliability demonstrations in accordance with MIL-STD-781. These demonstrations shall test one antenna (with matched filters) and one rotary joint with APG's to demonstrate that the reliability requirements of 3.2.3 have been met. Reliability production acceptance (sampling) tests are not required.

a. The test level for exercising the equipments for all demonstrations shall be test level E of MIL-STD-781 modified as follows:

   1. temperature limits: -50°C to +70°C,

   2. vibration limit: 1.0G ±10%,

b. The test plan shall meet the requirements listed below and need not be one of the test plans listed in MIL-STD-781c.

1. For a period of 600 hours an antenna (with filters) shall be electrically exercised and one rotary joint shall each be electrically and mechanically exercised.

2. The antenna shall be fully assembled with the filters mounted in their normal operating configuration.

3. The rotary joint shall be exercised as a fully assembled unit.

4. At the conclusion of the antenna exercise period, the tests of 4.2.1.1 and 4.2.1.2 shall be performed. Any test measurement that does not meet all require-ments of this specification shall constitute a failure of the antenna reliability demonstration.

5. At the conclusion of the rotary joint exercise period, the tests of 4.2.1.3 shall be performed. Any test measurement that does not meet all requirements of this specification shall constitute a failure of the antenna reliability demonstration.

6. No preventive maintenance may be performed at any time during the reliability demonstration. However, if the contractor so elects, the chamber may be opened and test measurements may be performed at intervals not more than once per week. The time that the chamber is open will not count toward the required 600-hour tests duration. The FAA will witness all such test measurements. Three days notice of the commencement of these tests will be provided to the FAA by the contractor.

A detailed test procedure for the reliability demonstration tests shall be prepared in accordance with MIL-STD-781 and submitted to the government for approval 60 days prior to testing. Reliability records shall be kept in accordance with 5.12 of MIL-STD-781 and FAA handbook 6040.10.

<u>4.2.4</u> <u>Maintainability demonstration</u>. The maintainability demonstration shall be limited to the verification of maintenance task times shown in the maintainability data base and employed in maintainability predictions and shall be in accordance with MIL-STD-471 (Phase II). The government shall select task times to be demonstrated. Fault simulation shall not be employed. The demonstration of maintenance task times shall be comprehensive

and shall emphasize the difficulties inherent in working on the equipments as mounted on ARSR's (see 4.1.2.1 of MIL-STD-471). The maintainability demonstration shall be staffed by contractor personnel (to include the test director). All demonstrations shall be witnessed by government personnel.

Whenever a maintenance task time from the maintainability demonstration exceeds the predicted time by more than 20%, the maintenance task time from the maintainability demonstration shall be used as the time required for the task and the maintainability prediction of 3.2.4.1 shall be used to show that all maintainability requirements are met when the new task time is used in prediction.

The contractor shall submit a test plan in accordance with 4.2.6 of MIL-STD-471 based upon the maintenance tasks selected by the government for demonstration. These tasks shall be selected from a draft of the contractor's detailed maintenance plan and preliminary maintainability data base information. The contractor's maintenance program plan shall provide for the timely submittal of the necessary draft maintenance plan, preliminary maintainability data base, and test plan. The test plan shall be submitted 30 days prior to the scheduled date for maintainability demonstration testing.

4.2.5 Factory tests. The following production tests shall be conducted in accordance with 4.3.4 of FAA-G-2100c.

4.2.5.1 Antenna production tests. The following electrical tests shall be performed on each antenna:

Test	Reference paragraph
Sum elevation patterns	3.2.1.1.1.1
Difference elevation patterns	3.2.1.1.1.2
SLS elevation patterns and phase	3.2.1.1.1.3
Sum azimuth patterns	3.2.1.1.2.1
Difference azimuth patterns	3.2.1.1.2.2
Error azimuth patterns and post-hybrid phase	3.2.1.1.4
SLS azimuth patterns	3.2.1.1.2.3
Cross-polarization	3.2.1.1.3
Gain	3.2.1.1.1.1
Pulse distortion	3.2.1.2.2
Squint and skew	3.2.1.1.7

All sum and SLS patterns shall be measured at 1030 and 1090 MHz. Difference patterns shall be measured at 1090 MHz only.

4.2.5.2 Filter production tests. Each matched group of three antenna filters shall be subjected to the following electrical tests to demonstrate compliance with 3.2.1.3 and 3.2.1.3.1.

Tests

Pass-band attenuation
Stop-band attenuation
VSWR
Phase shift (tracking)
Insertion loss (tracking)

4.2.5.3. Rotary joint production tests. Each rotary joint with APG's shall be subjected to the following electrical tests following 168 hours of continuous rotation at 17 rpm.

Test	Reference paragraph
VSWR	3.2.1.5.2
Insertion loss	3.2.1.5.2
Phase and amplitude tracking (Channels 4&5, 4&6, 7&8, 7&9)	3.2.1.5
Pressure leakage	3.2.2.4.2
Pulse shape tracking	3.2.1.5

During the 168 hour Pulse shape tracking run-in of the rotary joints, all azimuth pulse generator (APG) mechanical drivers shall be loaded to supply 30 inch-ounces of torque to external sinks. In addition, all slip ring circuits shall carry the specified current at 60 Hz throughout the 168 hour test. At the end of the run-in it shall be established that the slip rings and brushes are functioning normally and that all APG drives meet the following requirements when an azimuth pulse generator is mounted in its normal operating position and the rotary joint is rotated at 17 rpm ±10%.

			ACP	ARP
a.	Pulse-to-pulse jitter (measured at 50% amplitude points)		±10% of nominal spacing	±20% of nominal spacing
b.	Pulse count:	12 bit	4096 per 360°	1 per 360°
		14 bit	16384 per 360°	1 per 360°

5. PREPARATION FOR DELIVERY

5.1 General.

The antenna shall be packed and shipped fully assembled.

5.2 Preservation and packaging. Items that are not contractor installed shall be preserved, packaged, and marked in conformance with specification, MIL-E-17555, Level A.

5.3 Packing and marking. Parts shall be paacked and marked in accordance with MIL-E-17555, Level B.

6. NOTES

6.1 Definitions.

The precise meanings of the various terms used in this specification are delineated in the following paragraphs.

6.1.1 Vertical. A vertical line at any point is the line defined by the string supporting a nonmagnetic plumb bob. A vertical plane is any plane containing a vertical line.

6.1.2 Horizontal. A horizontal plane is any plane for which the normal is a vertical line.

6.1.3 Elevation angle. The elevation angle of any directed line originating at a point P is the smaller angle between the line and the horizontal plane through P as measured in the vertical plane which includes the line. The elevation angle is positive if the line is directed above the horizontal plane at point P and is negative if the line is directed below the horizontal plane at point P.

With reference to the antenna patterns specified herein, gains and patterns are specified and shall be measured along directed lines from the geometrical center of the antenna aperture to the point of observation (or the point at which the antenna range source is located). The elevation angle associated with any such specification or measurement shall be the corresponding elevation angle of this directed line if the antenna were mounted in its normal operating orientation with the underside -6 dB point of the principal elevation plane sum pattern on the horizon (that is, on the horizontal plane passing through the geometrical center of the aperture).

6.1.4 Azimuth angle. The azimuth angle of any directed line originating at a point P is the angle, measured in the horizontal plane through P, of the intersection of the vertical plane containing the line and the horizontal plane through point P. The angle of this intersection shall be measured positive clockwise (as viewed from above) from a specified or convenient reference direction (i.e., some other horizontal line through P).
With reference to the antenna patterns specified herein, gains

and patterns are specified and shall be measured along directed lines from the geometrical center of the antenna to the point of observation (or the point at which the antenna range source is located). The azimuth angle associated with any such specification or measurement shall be the corresponding angle of the line of observation if the antenna were mounted in its normal operational orientation with the underside -6 dB point of the principal elevation plane sum pattern on the horizon. All pattern azimuth angles are measured positive clockwise from the intersection of the principal elevation plane with the horizontal plane through the center of the array.

6.1.5 Principal elevation plane. With the antenna mounted in its normal operating orientation, the principal elevation plane is the vertical plane passing through the center of the aperture and the peak of the directional sum pattern at 1030 MHz.

6.1.6 Sidelobe suppression (SLS). SLS is a technique for suppression of transponder replies to interrogations by the side lobe radiation of the directional pattern. The interrogation mode pulse pair, P1 and P3, is radiated by the directional pattern. The P2 pulse radiated by the SLS pattern occurs at a specific time interval after the first interrogation pulse, P1, and at a fixed amplitude ratio with P1. The airborne radar beacon transponder contains circuitry for amplitude comparison and pulse spacing recognition of pulse P1 and P2 and suppresses replies whenever the amplitude of P2 equals or exceeds the amplitude of P1.

6.1.7 Global peak and local peak gains. The global gain of the antenna is the maximum gain over all elevation and azimuth angles. The angle at which the peak gain occurs is defined to be the angle midway between the two points, one on either side and adjacent to the peak gain, at which the gain is 0.5 dB below the peak gain. A local peak is the point at which the antenna gain achieves a maximum over some restricted region (e.g., over all azimuth angles at some specified elevation angle). The angle at which a local peak occurs is defined to be the angle midway between the two points, one on either side and adjacent to the local peak, at which the gain is 0.5 dB below the local peak gain.

6.1.8 Pattern nulls. A pattern null is a point at which the pattern gain achieves a minimum over some restricted region (e.g., over all azimuth angles at some specified elevation angle). The angle at which the null occurs is defined to be the angle midway between the two points, one on either side and adjacent to the null, at which the gain is 10 dB above the null gain. If the null depth is less than 20 dB, the angle at which

the null occurs will be measured as described above except the two measurement points shall be at the gain level 2 dB above the null gain.

6.1.9 Phase center. The phase center is the center of curvature of the wave front of the radiation for the pattern of interest as measured in some specified region.

6.1.10 Sum pattern. The sum pattern is another name for the directional pattern. The directional pattern is the pattern for radiating Mode S/ATCRBS interrogations and receiving conventional Mode S/ATCRBS replies.

6.1.11 Difference pattern. The difference pattern is another name for the monopulse pattern. The monopulse pattern will be used in conjunction with the sum pattern to estimate the azimuth angles of transponders within the main lobe of the directional pattern.

6.1.12 Error pattern. The error signal is defined as the amplitude of the difference signal divided by the amplitude of the sum signal. The difference signal is the RF return from the difference pattern (measured at the difference port of the antenna) and the sum signal is the RF return at the sum port. The error pattern is the graph of the error signal versus the azimuth angle of the far-field RF source generating the sum and difference signals.

6.1.13 SLS pattern. The SLS pattern radiates the side lobe suppression (P2) pulses.

6.1.14 Sidelobe. A sidelobe is any radiation lobe (local maximum) in the front hemisphere (within 90 degrees azimuth of the principal elevation plane) other than the intended (sum and difference lobes). Beam shoulders (local maxima immediately adjacent to the main lobe which are less than 1 dB high as measured from the peak of the shoulder to the base of the null between the shoulder and the main lobe) are considered a part of the main lobe and hence are not sidelobes.

6.1.15 Backlobe. A backlobe is any radiation lobe in the back hemisphere.

6.1.16 Pattern slope. The sum, difference, or SLS elevation pattern slope measured along a prescribed angular coordinate at some reference point is defined as follows. Let G(0) be the gain (in dB) of the pattern at the reference point. Let E1 be the angle (along the prescribed coordinate) nearest the reference point at which the gain is (G(0) + 1 dB) and E2 be the angle nearest the reference point at which the gain is (G(0) - 1 db).

Then the slope of the pattern at the reference point is defined to be the slope of the straight line passing through the two points (E1, (G(0) + 1dB)) and (E2, (G(0) - 1dB)).

The SLS Azimuth pattern slope at some reference point shall be defined as follows:

Let G(1) be the gain (in dB) at a point one-third degree to the left of the reference point. Let G(2) be the gain (in dB) at a point one-third degree to the right of the reference point. The slope is defined as three halves the absolute value of the difference between G(1) and G(2).

The slope of the error pattern for positive (negative) azimuth angles is defined as the slope of the straight line passing thru the error pattern at the azimuth angle of the difference pattern null adjacent to the principal elevation plane and the positive (negative) azimuth angle at which the sum pattern is 2 dB below the local peak of the beam.

6.1.17 Relative field strength. The relative field strength is the field strength relative to the global or local peak of the pattern.

6.1.18 Standard ATCRBS/Mode S reply pulse. For the purposes of this specification, the standard ATCRBS/Mode S reply pulse has a rise time between 50 and 60 nanoseconds (from the 10 to 90 percent amplitude points), a fall time between 50 and 60 nanoseconds (from the 90 to 10 percent amplitude points), and a pulse duration between 300 and 350 nanosecnds as measured between the 90 percent amplitude points on the leading and trailing edges. The pulse amplitude is constant to within 10 percent of the peak amplitude over the pulse duration. The RF carrier of the pulse is any frequency between 1085 and 1095 MHz.

6.1.19 Post hybrid phase angle. The post-hybrid phase angle is the phase angle of the difference signal measured with respect to the phase angle of the sum signal where the reference planes of both signals are at the respective antenna input/output connectors.

6.1.20 Squint. The angular distance between the axis of antenna radiation and a selected geometric axis such as the axis of the reflector.

6.1.21 Skew. Variations in squint as a function of elevation angle.

ANTENNA TEST RANGE

A2.1 Introduction

This appendix is referenced in 4.1.2.1 of the main specification and establishes design guidelines and probe data requirements for the test range(s) that will be employed in verifying antenna performance.

The purpose of antenna testing is to determine how the antenna will perform under actual operating circumstances. For this reason, it is important to assess the characteristics of the antenna itself, and not of the antenna in one particular environment. Ideally, the test antenna would be placed in free space with a source antenna at a near infinite separation. This would permit measurement of the characteristics of the antenna in the absence of external interference and in an incident field uniform in both phase and amplitude. However, this is not possible and restrictions must be established on the actual test environment.

A test environment in which the phase taper across the test antenna is minimal must be provided. If this taper is too severe, the antenna does not integrate the energy over its surface in the same manner as it does at extremely large separations and the resulting patterns are distorted. A commonly employed criterion is to restrict this phase taper to a maximum of $\pi/8$ radians or 22.5 electrical degrees. Secondly, the amplitude taper across the antenna must be maintained at a minimal amount. The primary effect of moderate amplitude taper in the incident field is to produce errors in the relative levels of the minor lobes of the radiation pattern and to indicate a gain slightly less than the actual value.[1] For most antennas to be tested, an incident field which is constant

[1] Chastain, J. B., et al, Investigations of Precision Antenna Pattern Recording and Display Techniques., Section 2.104/5-912, April 1963

in amplitude to within 0.25 decibel over the aperture area should ensure negligible error. Finally, all extraneous energy resulting from reflections from surrounding objects, diffraction effects, etc. must be kept to, or below, a predetermined level to meet the allowable error requirements for the tests to be made. In addition to the above restrictions which are electromagnetic in nature, test fixtures must have the mechanical stability and positioning accuracy to perform the required tests. These mechanical requirements are very important, but this discussion will be restricted to electromagnetic characteristics and the above electrical considerations shall be of paramount importance. In the following sections, the elevated range test configuration will be discussed. The design of an elevated range should be directed toward suppressing the unavoidable reflections from the earth's surface by a combination of directive source antennas, large source and receive tower heights, diffraction fences, and judicious positioning of the antenna under test.

A2.2 Source Antenna Illumination Tapers

A2.2.1 Phase Variation of Incident Field

The allowable phase curvature across an antenna under test depends almost entirely on its separation from the source antenna. If the receiving antenna is in the far zone of the transmitting antenna, the phase front of the approaching wave deviates very little from a section of a spherical surface centered on the transmit antenna over the main portion of the main lobe.[2]

This can be seen in Figure A2.1 which is a graph of the calculated phase deviation in degrees over a spherical surface through the main lobe of the beam produced by a circular transmitting aperture.[3] A 30 db Taylor distribution[4] is assumed and four different distances are assumed from the transmitting antenna to the spherical surface: d^2/λ, $2d^2/\lambda$, $4d^2/\lambda$, and infinite where d is the aperture width of the transmitting antenna.

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[2] Ibid.

[3] Hollis, J. S., et al, Microwave Antenna Measurements, Scientific-Atlanta, Inc., 1969, p 14-6.

[4] Hansen, R. C., "Tables of Taylor Distributions for Circular Aperture Antennas," IRE Transactions on Antennas and Propagation, Vol. AP-8, pp. 23-26, January 1960.

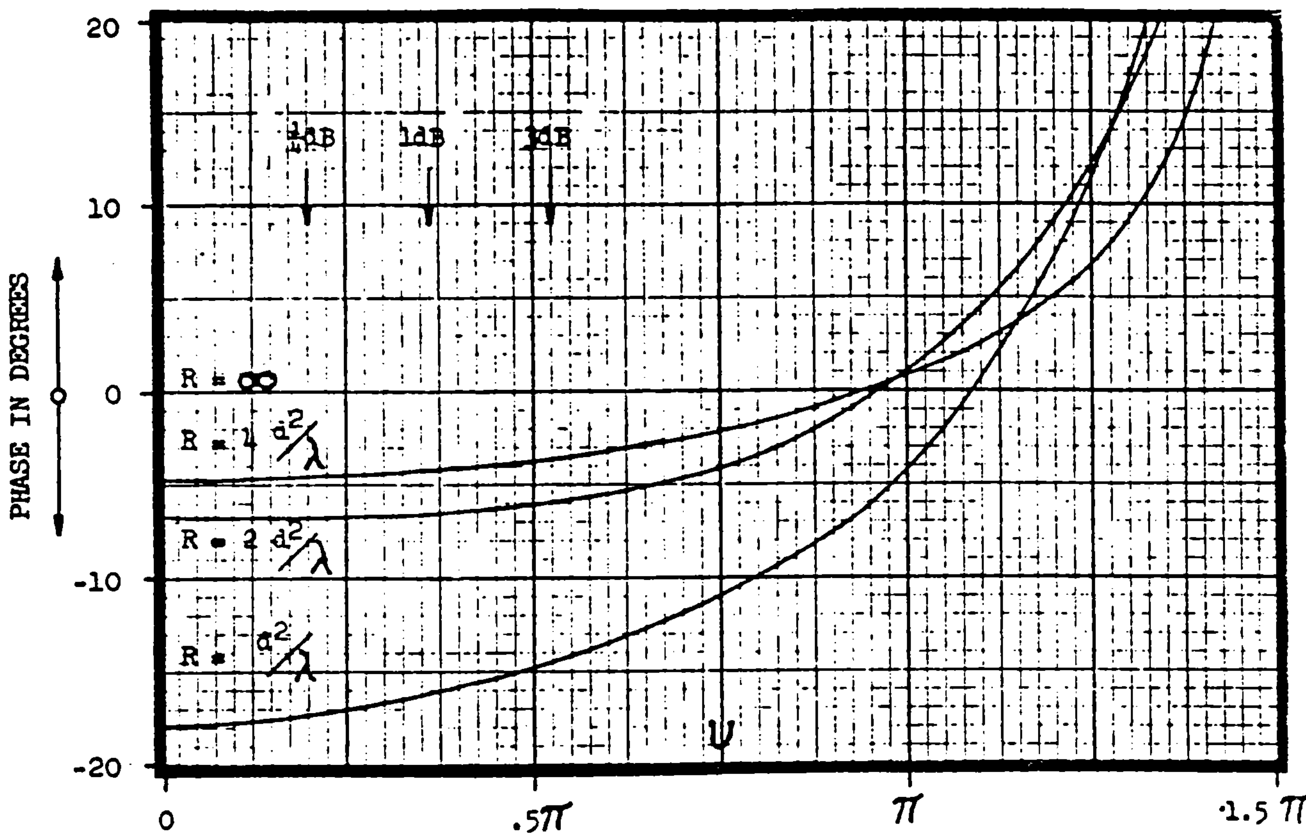

Figure A2.1 Deviation of transmitted phase front from spheres centered on transmitting antenna. R is radius. A 30 dB Taylor aperture distribution is assumed.

The main lobe extends from approximately $U = -1.6\pi$ to $U = 1.6\pi$, where $U = (\pi/\lambda)\, d \sin\theta$. Even at a range as small as d^2/λ, the phase front is spherical to within 2 degrees between the 1 decibel points of pattern; this condition is typical of reasonably focused symmetrical antennas. When the transmitting antenna is focused at the test range, the phase front will be essentially that for $R = \infty$. When the transmitting antenna is significantly defocused, slightly greater phase variation will be experienced. In any event, the deviation of the phase front from spherical between the 1/4 decibel points of the beam will be small.

From Figures A2.1 and A2.2, it can be seen that the phase variation across the area occupied by a test antenna is almost entirely due to the spherical nature of the wave emanating from the transmitter antenna. This deviation can be calculated from the geometry of Figure A2.2. D is the maximum aperture dimension of the antenna under test and R is the distance from the test antenna to the center of phase of the source antenna.

From the figure,

$$(R + \Delta)^2 = R^2 + (D/2)^2 \qquad (2.1)$$

hence

$$\Delta^2 + 2R\Delta = D^2/4 \qquad (2.2)$$

or

$$\Delta = D^2/8R \qquad (2.3)$$

for $\Delta \ll 2R$.

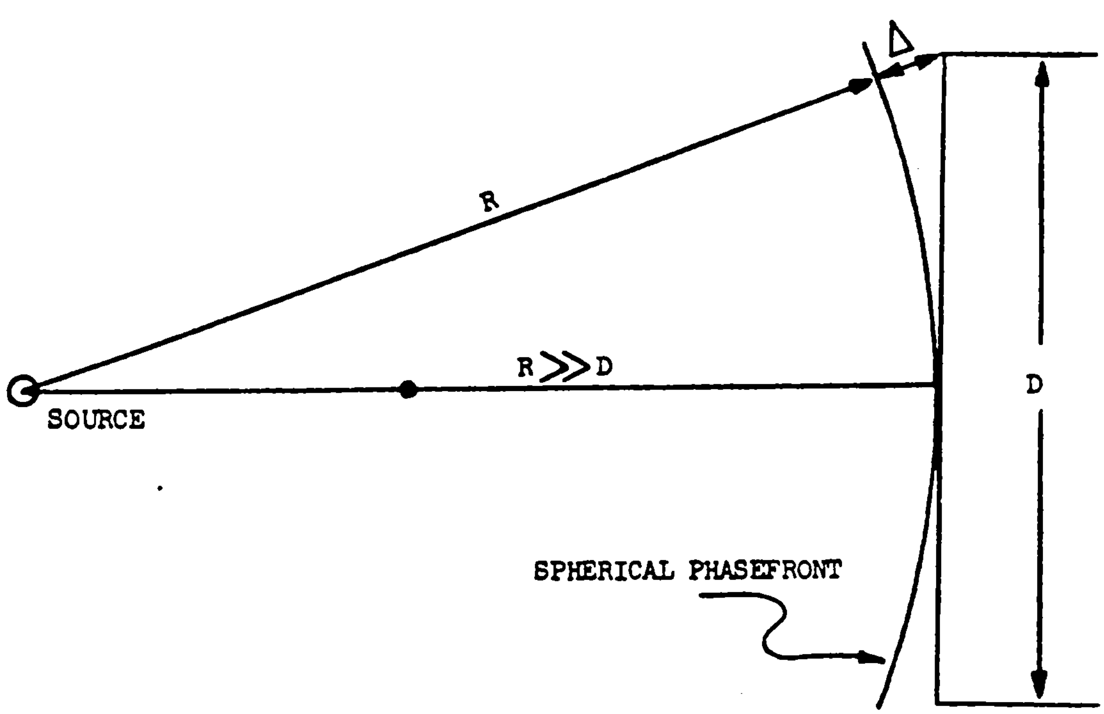

Figure A2.2 Section through incident phasefront at a test separation R>>D.

The resulting phase deviation at the extremes of the test aperture as compared to that at the center is then

$$\delta = \frac{2\pi}{\lambda} (D^2/8R) \text{ radians.} \tag{2.4}$$

A commonly employed criterion is a phase restriction of 22.5 degrees, ($\delta = \pi/8$), which when substituted into equation (2.4) yields:

$$R \geq 2D^2/\lambda \ . \tag{2.5}$$

If antenna measurements are made at a range of $2D^2/\lambda$, there will be a significant departure of the nulls of the radiation pattern and the location and levels of the minor lobes from their infinite-range values. The amount of the deviation depends on the original side-lobe level and structure. D. R. Rhodes[6] calculated that at a range of $2D^2/\lambda$ the first null of the pattern produced by a rectangular aperture with uniform illumination has a level of about -23 decibels instead of $-\infty$ decibels. This deviation is caused only by phase-error effects; the incident-wave amplitude over the test aperture was assumed constant. The infinite range pattern in the above case has a $\frac{\sin x}{x}$ configuration with a first-lobe level of about -13 decibels.

Figure A2.3 is a graph showing the infinite range pattern of a circular aperture with a 30 decibel Taylor distribution and the patterns at separations of $2D^2/\lambda$ and $4D^2/\lambda$ as calculated by a Fourier Integral Computer.[7] If an antenna such as this is adjusted for optimum focus at a range of $2D^2/\lambda$ or $4D^2/\lambda$ for example, the antenna will be lightly defocused for operation at extreme ranges. It is evident that, for extreme accuracy of the infinite-range side-lobe structure, measurements must be made at a range which is appreciably greater than $4D^2/\lambda$.

The above separation criterion is equally valid for the ground reflection mode of operation. In the case of the ground reflection range, R is the separation between the source-image array and the test aperture. [8, 9]

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[6] Rhodes, D. R. "On Minimum Range for Radiation Patterns," Proc. I. R. E. Vol. 42, No. 9, pp 1408-1410, September 1954.

[7] Hollis, J. S. et al, op cit.

[8] Hollis, J. S., et al, A Precision Ground-Reflection Antenna Boresight Test Range prepared for presentation at 14th Annual Symposium on USAF Antenna Research and Development, University of Illinois, October, 1964.

[9] Lyon, T. J., et al, Evaluation of the NASA-KSC-MILA RF Boresight Test Facility at X-Band and S-Band, Final Report, Contract No. NAS10-2103, May, 1966.

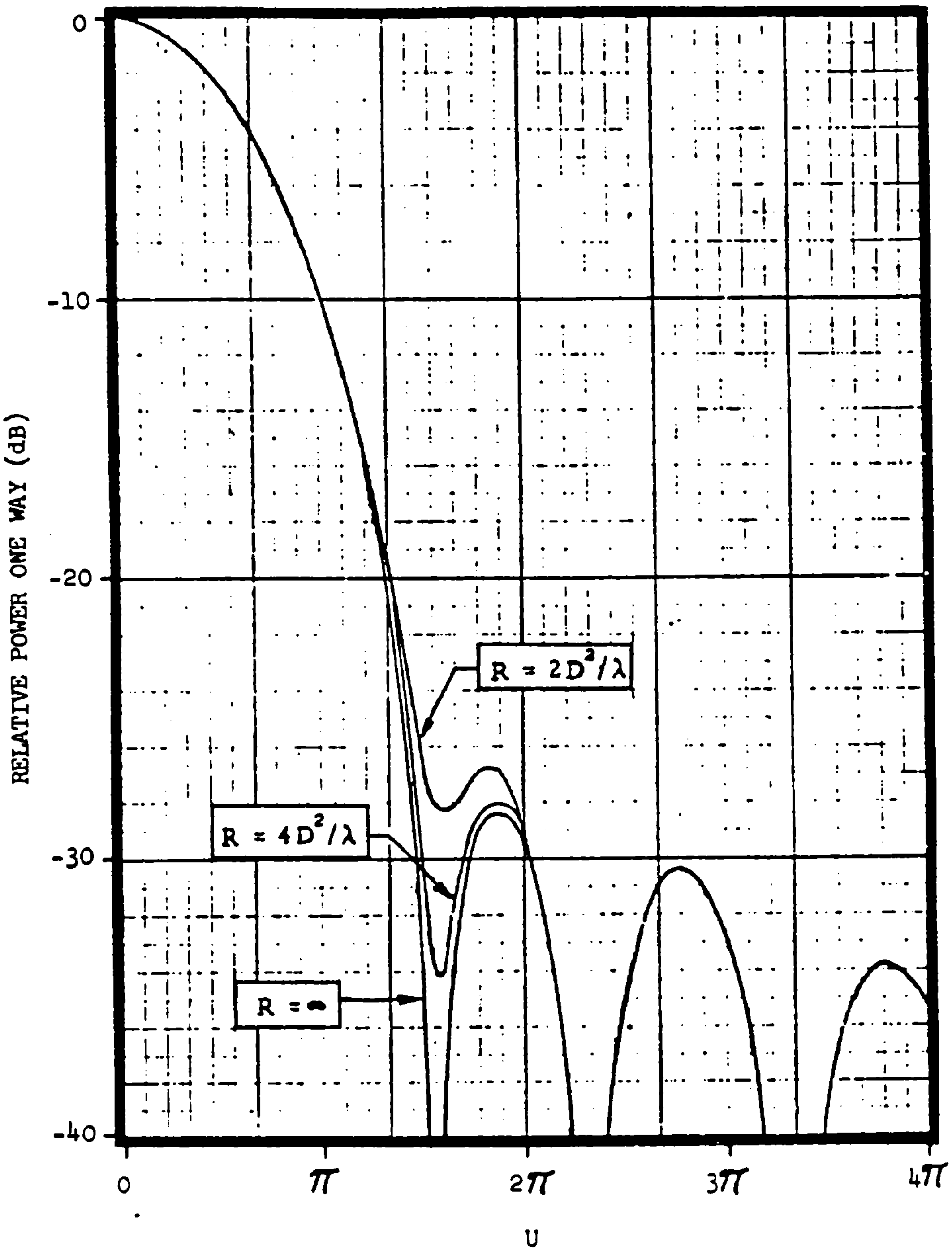

Figure A2.3 Calculated radiation patterns of a paraboloid with quadratic phase errors encountered in measuring at three ranges as indicated.

Actual calculated patterns for these various test separations are shown in Figures A2.4 through A2.7. A 10-decibel cosine aperture illumination function on transmitting was assumed for these patterns. This illumination function is very similar to that of many commonly used microwave antennas. The true pattern for the antenna is shown in Figure A2.4 which represents illumination by a plane wave of uniform amplitude. As the test separation is decreased, as is shown sequentially in Figures A2.5 through A2.7, the nulls fill in and the sidelobes are raised. This is accompanied by a lower measured gain for the antenna. More will be said about this gain reduction in the following section.

A2.2.2 Amplitude Taper Over the Test Aperture

The effect of amplitude taper of the incident field over the test aperture on receiving can be considered from the viewpoint of reciprocity.[10] Variation of the amplitude of the field over the aperture on receiving is analogous, within the accuracy of the aperture field approach, to the modification of the aperture illumination by the primary feed on transmitting. For example, consider the pattern of an antenna whose feed would produce an aperture illumination f (θ,r) on transmitting, where (θ,r) indicates position in the aperture. If illuminated on receiving by a source antenna which produces over the test aperture an amplitude taper g (θ,r), the measured pattern would be that of a transmitting antenna illuminated by a feed which produces an illumination of f (θ,r) g (θ,r) over the aperture. If g (θ,r) is constant in amplitude and phase over the aperture, the measured pattern will be the same as the infinite-range pattern for the illumination f (θ,r). The greater g (θ,r) deviates from constant, the greater will be the deviation of the measured pattern from the infinite-range pattern. The quantitative effect of nearly constant functions g (θ,r) cannot be determined, however, without assumption of f (θ,r).

Figure A2.8 is a calculated infinite-range pattern of a circular aperture with a 10-decibel cosine taper distribution as tested with a source antenna which produces a circularly symmetric amplitude taper of 0.5 decibels at the periphery.[11] The taper is assumed to have a $\frac{\sin x}{x}$ form which closely approximates a large portion of the transmitted beam of most narrow-beam antennas. The effects of amplitude taper on the calculated patterns are not nearly as dramatic as the effects of phase taper caused by short range lengths. The calculated patterns show nearly identical close-in sidelobes. The reduction in gain is about 0.15 decibel for the 0.5 decibel taper.

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[10] Chastain, J. B., et al, op cit

[11] Hollis, J. S., et al, op cit

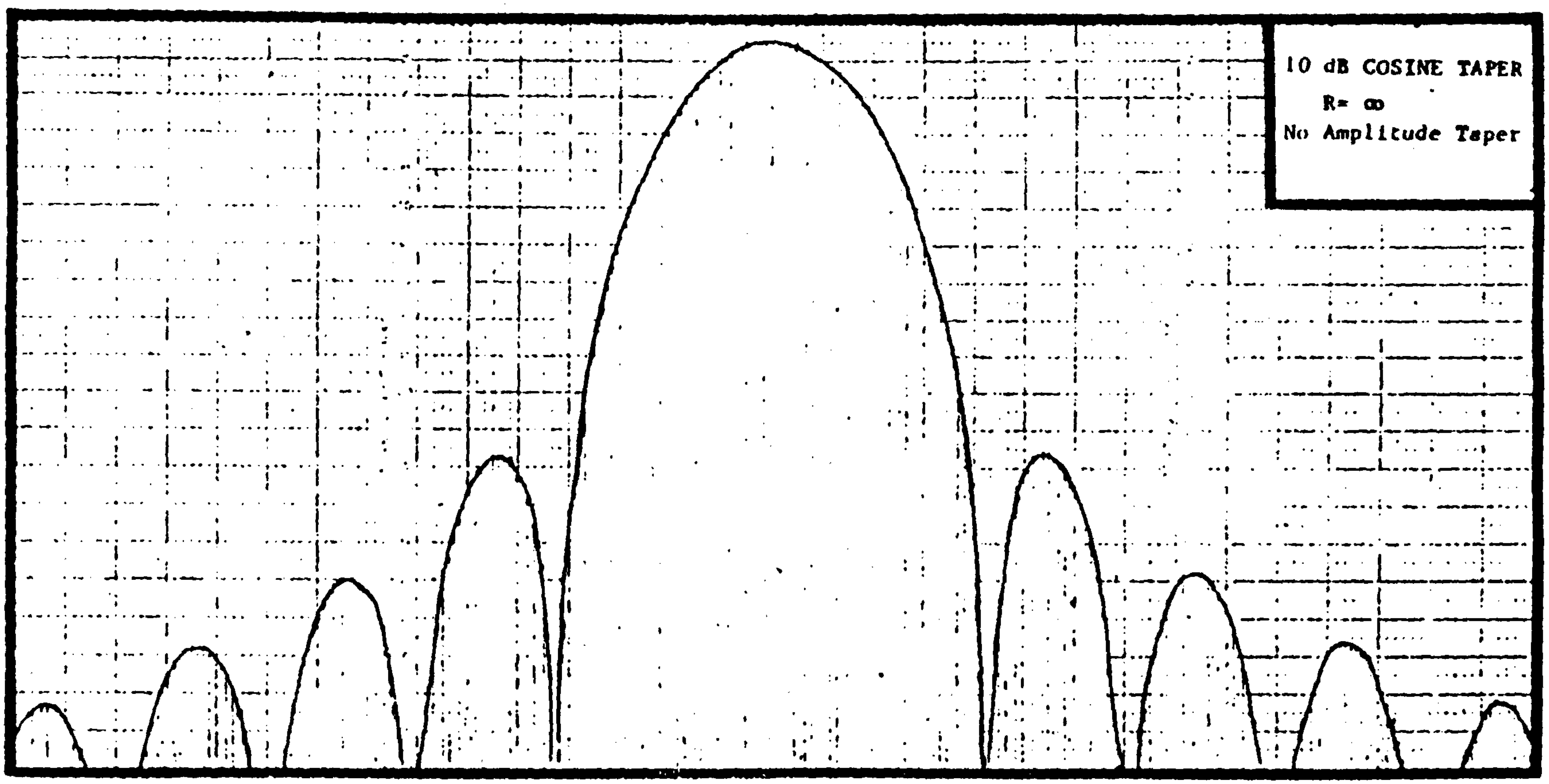

Figure A2.4 Calculated pattern of an antenna with a 10dB C ine feed illumination function.

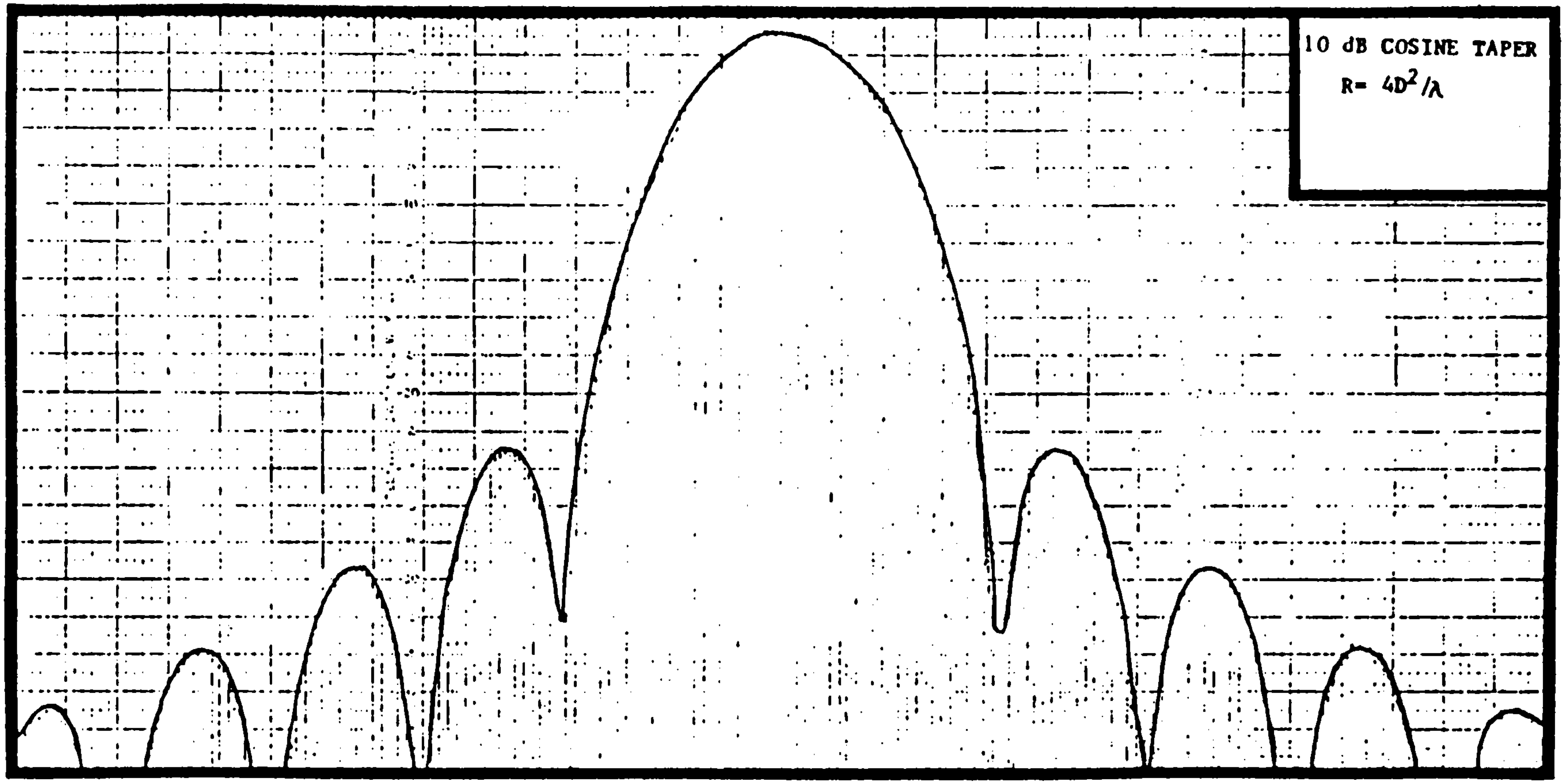

Figure A2.5 Calculated pattern of an antenna with a 10dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of $4D^2/\lambda$.

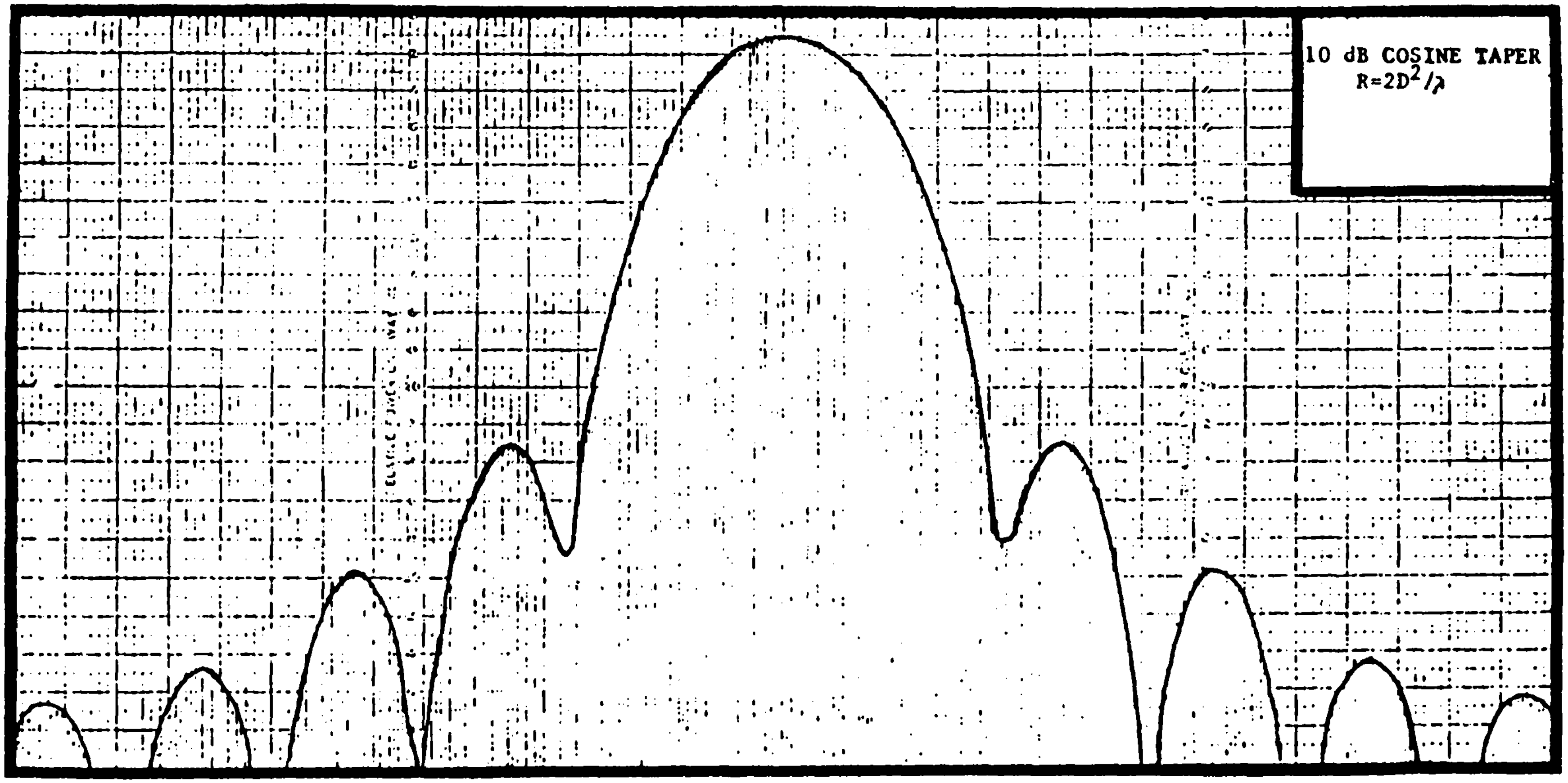

Figure A2.6 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of $2D^2/\lambda$.

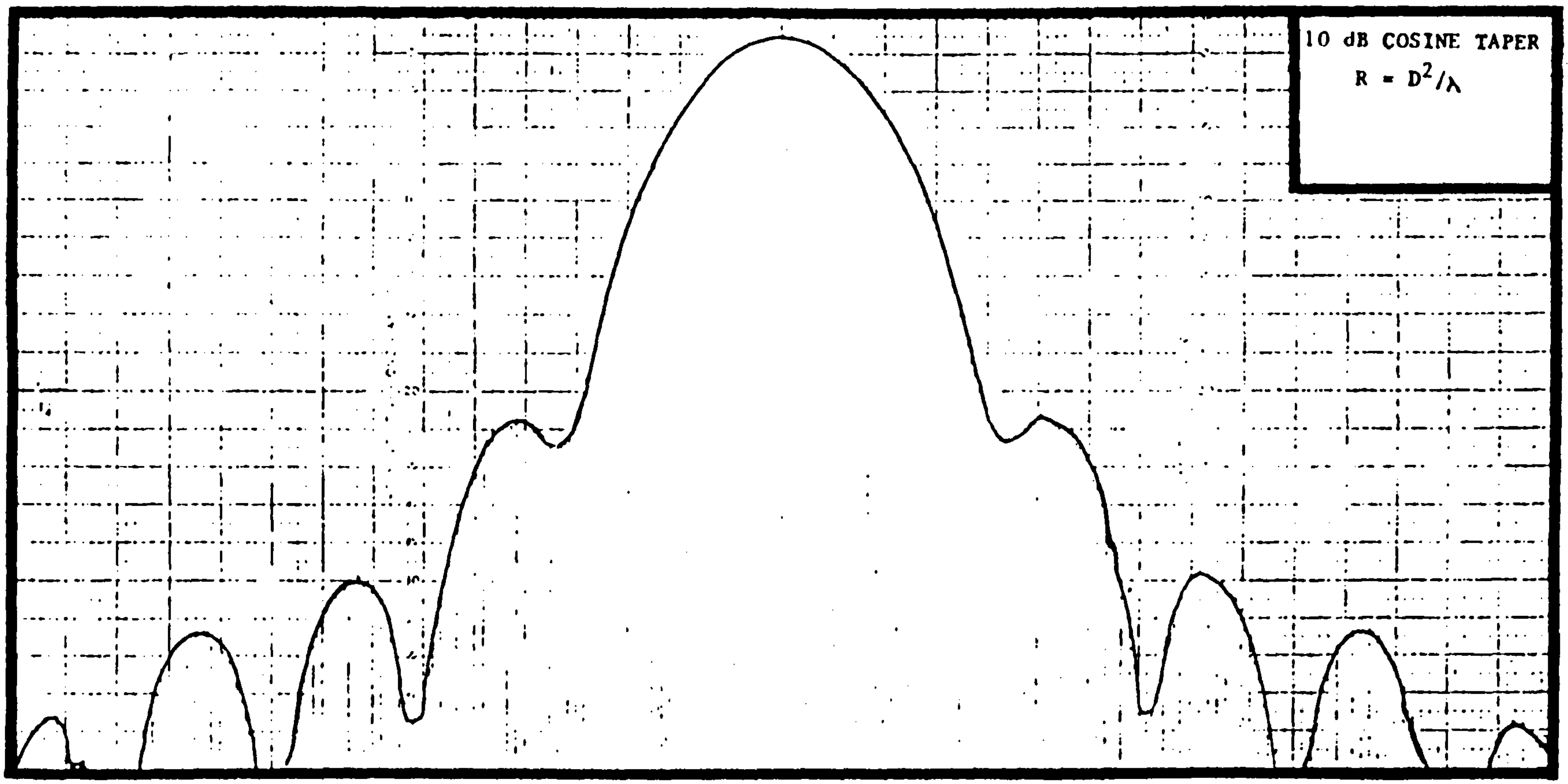

Figure A2.7 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of D^2/λ.

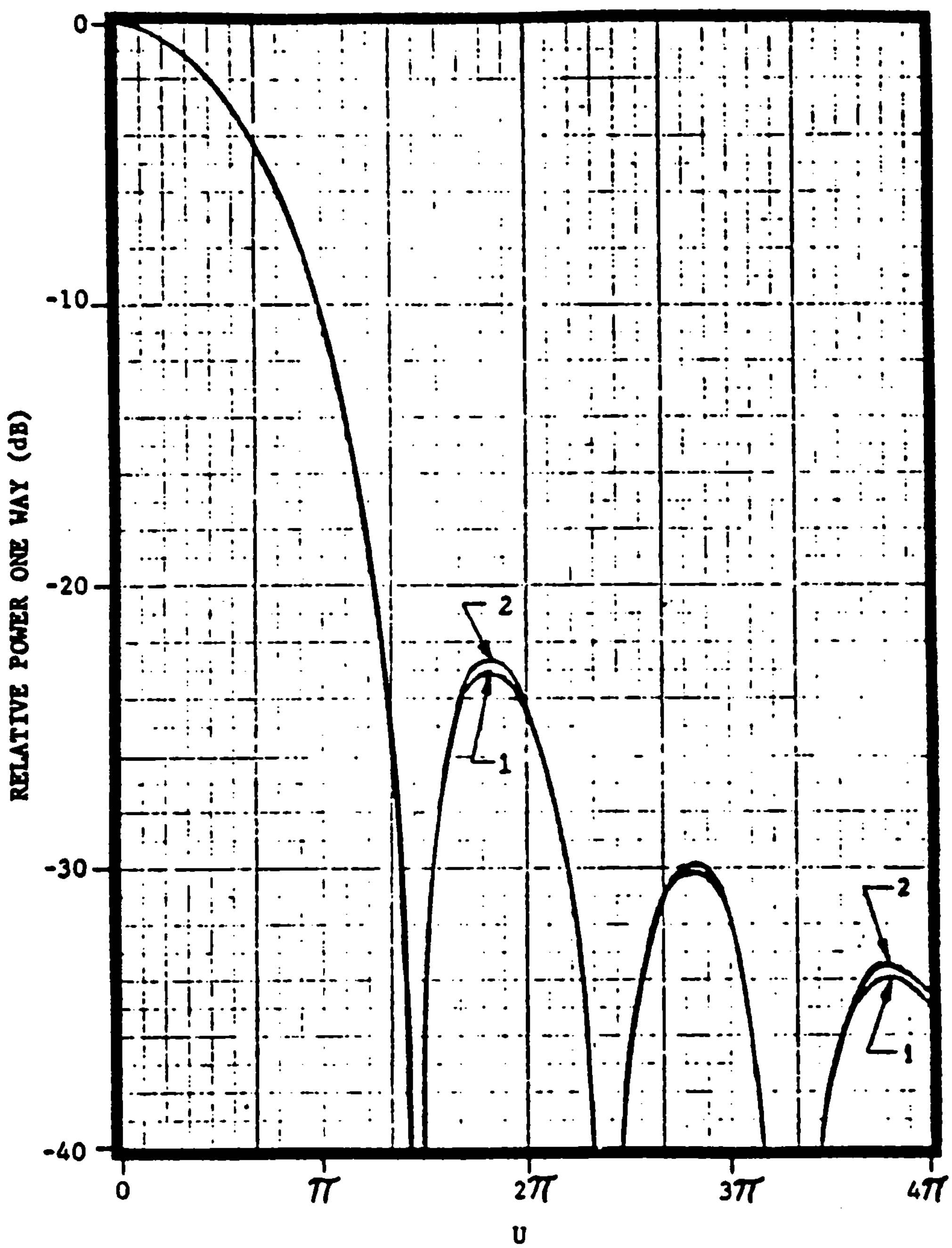

Figure A2.8 Calculated radiation patterns of a paraboloid with a 10 dB aperture illumination taper; (1) Measured with a 0.5 dB (Sin x)/x taper of the source antenna pattern, and (2) with no taper.

The decrease in measured gain caused by aperture taper is determined by the amount of taper and by the aperture illumination function of the antenna under test. For typical illumination functions, estimates of decrease in measured gain are 0.1 decibel for a 0.25 decibel taper and 0.04 decibel for a 0.1 decibel taper. A taper of less than approximately 0.01 decibel would be required to limit the decrease in gain to 0.01 decibel. A taper of 0.01 decibel would require a transmitting antenna 3-decibel beamdwidth of approximately 16 times the width of the aperture under test.

Calculated values of these decreases in gain as functions of both phase and amplitude tapers are presented in Tables A2.1 through A2.4 for four different aperture illumination functions. It can be seen in these tables that the correction factors are of sufficient consistency with illumination function that reasonably accurate corrections can be made to measured gain using these tables alone.

A criterion of 0.25 decibel is commonly employed for the limit of the amplitude taper over the test aperture. Calculated patterns reveal little distortion to the expected pattern as a result of small amplitude tapers in the illuminating field. The calculated pattern for the 0.25 dB taper is essentially the same as the one for the uniform field. However, if a source antenna is employed which is calculated to produce a taper of the field over the test aperture, it is essential that the transmitting antenna be directed such that the peak of its beam is centered on the antenna under test to prevent excessive and asymmetrical illumination taper with a resultant increase in the measuring error.

It is important to note that error from symmetrical amplitude taper within the accepted criterion of 0.25 decibel does not produce a defocusing type of error but a small modification of the measured side-lobe levels and an error in measured gain. Figure A2.9 shows the effect of both a 0.25 decibel amplitude taper produced by the directivity of a transmit antenna and a 22.5° phase taper produced by a range length of $2D^2/\lambda$. The antenna is truly characterized by the pattern shown in Figure A2.4. A gain reduction of 0.154 decibels would accompany this pattern distortion.

TABLE A2.1

GAIN REDUCTION CORRECTIONS
CONSTANT ILLUMINATION FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x)								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.224	.249	.276	.299	.325	.349	.469	.596	.720
2	.056	.080	.108	.130	.156	.181	.300	.427	.551
3	.025	.050	.076	.099	.125	.150	.269	.396	.520
4	.014	.139	.066	.089	.114	.139	.258	.386	.509
5	.009	.034	.061	.084	.109	.134	.253	.381	.504
6	.006	.031	.058	.081	.106	.131	.250	.378	.502
7	.005	.029	.056	.079	.105	.129	.249	.376	.500
8	.003	.028	.055	.078	.104	.128	.248	.375	.499
9	.003	.028	.054	.077	.103	.128	.247	.374	.498
10	.002	.027	.054	.077	.103	.127	.246	.374	.498
	0	.025	.052	.075	.100	.125	.244	.372	.495

TABLE A2.2
GAIN REDUCTION CORRECTIONS
10 dB COSINE FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.206	.226	.248	.267	.288	.308	.405	.508	.609
2	.051	.072	.094	.112	.133	.154	.251	.355	.456
3	.023	.043	.065	.084	.105	.125	.223	.327	.428
4	.013	.033	.055	.074	.095	.115	.213	.317	.418
5	.008	.029	.051	.069	.090	.110	.208	.312	.413
6	.006	.026	.048	.067	.088	.108	.206	.310	.411
7.	.004	.024	.047	.065	.086	.106	.204	.308	.409
8	.003	.024	.046	.064	.085	.106	.203	.307	.408
9	.003	.023	.045	.064	.085	.105	.203	.307	.408
10	.002	.022	.044	.063	.084	.104	.202	.306	.407
	0	.020	.042	.061	.082	.102	.200	.304	.405

TABLE A2.3
GAIN REDUCTION CORRECTIONS
10 dB $(1-\rho^2)$ ILLUMINATION FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.204	.224	.246	.265	.286	.307	.404	.509	.610
2	.051	.071	.093	.112	.134	.154	.252	.357	.459
3	.023	.043	.065	.084	.105	.126	.224	.329	.431
4	.127	.033	.055	.074	.096	.116	.214	.319	.421
5	.008	.029	.051	.070	.091	.111	.210	.315	.417
6	.006	.026	.048	.067	.089	.109	.207	.312	.414
7	.004	.025	.047	.066	.087	.107	.206	.311	.413
8	.003	.024	.046	.065	.086	.106	.205	.310	.412
9	.003	.023	.045	.064	.085	.106	.204	.309	.411
10	.002	.023	.045	.064	.085	.105	.204	.309	.411
	0	.020	.043	.062	.083	.103	.202	.307	.409

TABLE A2.4
GAIN REDUCTION CORRECTIONS
15 dB $(1-\rho^2)$ ILLUMINATION FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATIN FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.188	.206	.227	.244	.263	.282	.373	.470	.564
2	.047	.066	.086	.104	.124	.142	.234	.331	.425
3	.021	.040	.060	.078	.098	.116	.208	.305	.399
4	.012	.031	.051	.069	.089	.107	.199	.296	.391
5	.007	.026	.047	.065	.084	.103	.195	.292	.386
6	.005	.024	.045	.062	.082	.101	.192	.290	.384
7	.004	.023	.034	.061	.081	.100	.191	.288	.383
8	.003	.022	.042	.060	.080	.099	.190	.287	.382
9	.002	.021	.042	.060	.079	.098	.189	.287	.381
10	.002	.021	.041	.059	.079	.098	.189	.286	.381
	0	.019	.040	.057	.077	.096	.187	.285	.379

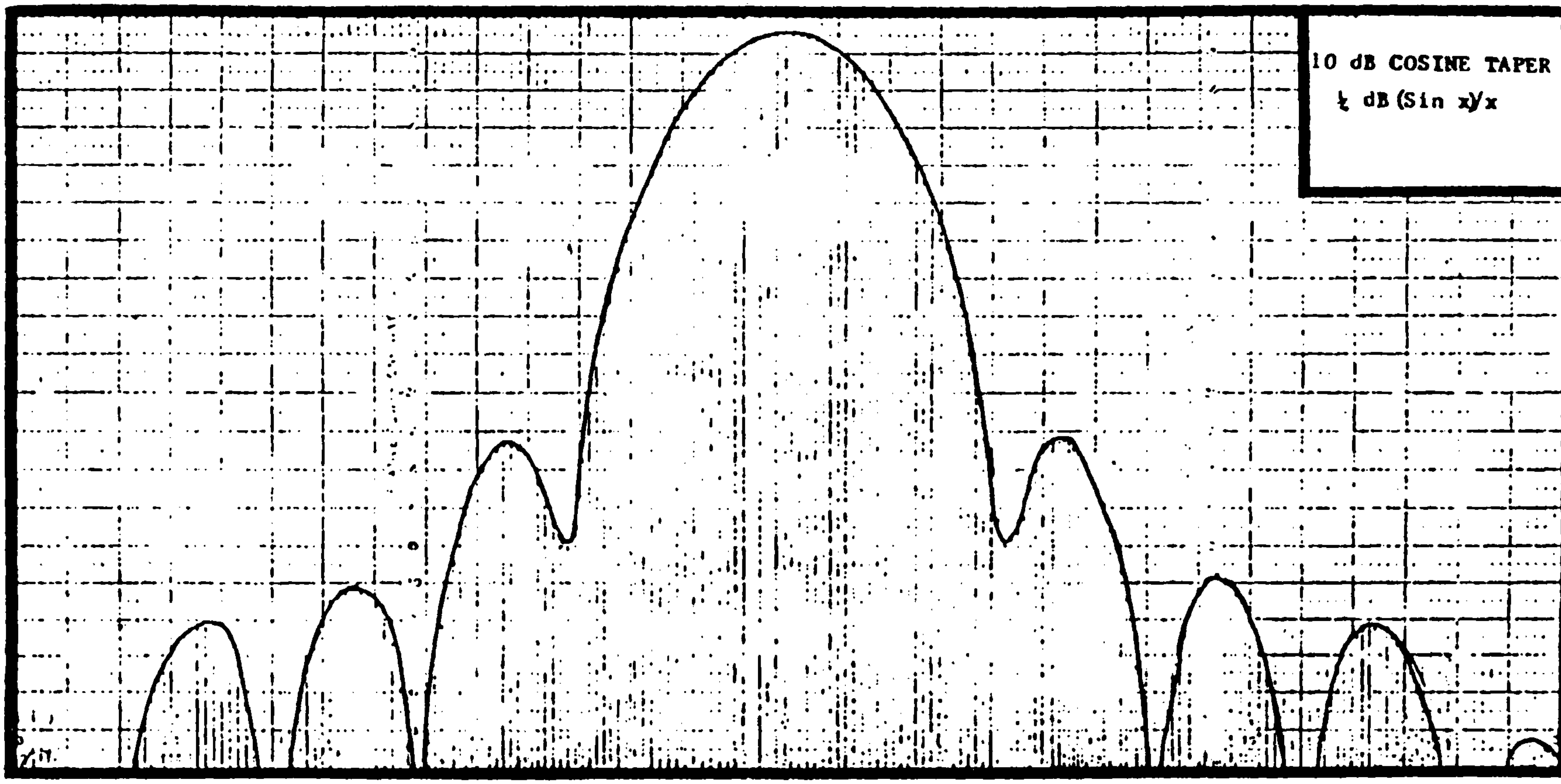

Figure A2.9 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase taper corresponding to a test separation of $2D^2/\lambda$ and a 0.25 dB amplitude taper of the illuminating field characterized by a (Sin x)/x distribution are assumed.

The geometry of the elevated range is shown in Figure A2.10. Neglecting reflected energy from the range surface which will be discussed later, the amplitude taper across the test antenna is controlled by the beamwidth of the transmit antenna. The angle α subtended by the antenna under test, denoted by D in the figure is given by:

$$\alpha = 2 \tan^{-1} (D/2R_o) \doteq D/R_o \qquad (2.6)$$

since $R_o \gg D$. The approximate 1/4 dB beamwidth θ (.25) of typical

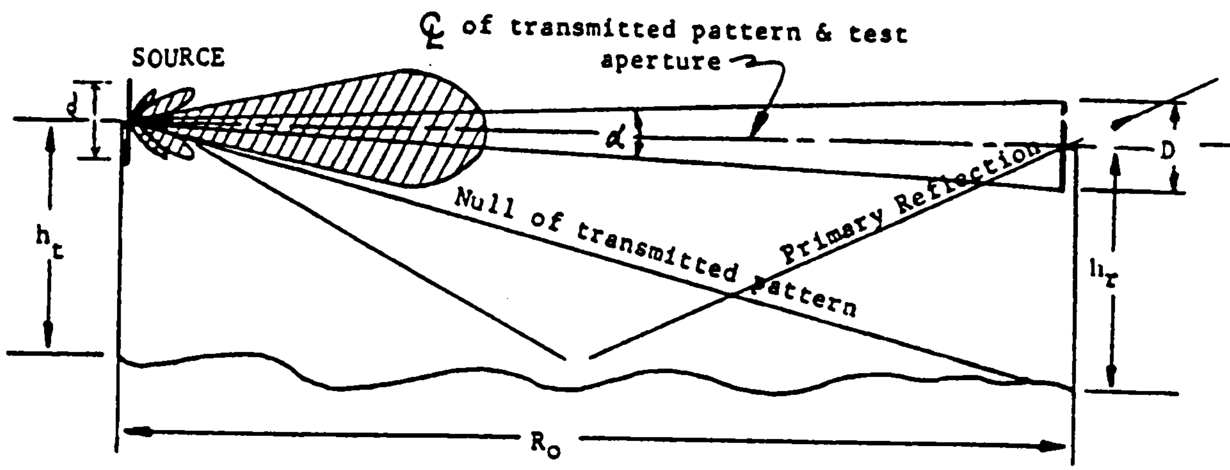

Figure A2.10 Elevated Antenna range geometry.

paraboloidal antennas commonly used for source antennas in the elevated mode is given by:

$$\theta\ (.25) \doteq 0.37\lambda/d, \qquad (2.7)$$

where d is the diameter of the source antenna and λ is the wavelength. It is readily seen that restricting the amplitude taper on the test antenna to a maximum of 0.25 dB is analogous to restricting the maximum diameter of the source antenna. Therefore:

$$0.37\lambda/d \gtrsim D/R_o \qquad (2.8)$$

or

$$d_{max} = 0.37\lambda R_o/D. \qquad (2.9)$$

A2.3 Extraneous Energy

The primary source of extraneous energy on an antenna range is reflections. A source of reflections that is common to all antenna ranges is the range surface. In the elevated mode of operation, the reflections from the vicinity of the range surface are minimized by clearing the vicinity of the range centerline of all obstacles such as trees, shrubs, etc.; selecting a source antenna of high directivity so as to allow only sidelobe energy to illuminate the range surface; and screening the surface from sidelobe energy by strategically placed conducting screens.

Refer to the geometry of Figure A2.10. Assume that the maximum amplitude taper of 0.25 dB exists across the aperture. The 0.25 dB beamwidth and main beam null separation for typical sin(x)/x microwave antenna patterns are related by

$$\theta\ (NULL) \doteq 8\,\theta\ (.25) \qquad (2.10)$$

If the main lobe energy is restricted from the range surface, then the lower limit for the null of the transmitted pattern is the base of the receiver tower and:

$$\theta\ (NULL) \lesssim 2\tan^{-1}(h_r/R_o) \doteq 2h_r/R_o \qquad (2.11)$$

since $R_o \gg h_r$. Combining this with equations (2.8), (2.9), and (2.10)

$$h_r \gtrsim 4\ D \qquad (2.12)$$

A practical design criterion for elevated test ranges is that the receive tower is 4.5 to 5 times the maximum dimension of the test aperture.

When R_o and h_r have been selected, the illumination criterion of equation (2.11) can be used to specify a minimum diameter of the source antenna.

$$\theta\ (NULL) \doteq 8\,\theta(.25) \doteq 8\,(.37\lambda/d) \lesssim 2h_r/R_o. \qquad (2.13)$$

This requires that:

$$d_{min} = 1.5\ \lambda R_o/h_r. \qquad (2.14)$$

Therefore a minimum source antenna diameter has been established due to the condition that only side-lobe energy be allowed to illuminate the ground. A maximum diameter was established to guarantee an acceptable amplitude taper across the test antenna. The restrictions on the size of the source antenna become:

$$1.5\lambda R_o/h_r \leq d \leq 0.37\lambda R_o/D. \qquad (2.15)$$

Many tests require suppression of range-surface reflections beyond that afforded by practical tower heights and source antenna sizes. Compliance with the criteria of equations (2.12) and (2.14) would probably result in an extraneous signal suppression of the order of -25 decibels relative to the direct-path signal level. The desired suppression can be calculated from the specified accuracy requirements by use of the expression

$$r = 20\log\left(1-10^{-a/20}\right) + G_D - G_R \qquad (2.16)$$

where

r is the ratio of reflected to direct-path signal levels in decibels ($r = 20\log E_R/E_D$),

a is the desired measurement accuracy in decibels,

G_D is the decibel gain of the test pattern in the direction of the direct-path signal, and

G_R is the decibel gain of the test pattern in the direction of the reflected signal.

It has been found that even over a very smooth surface, primary reflections can be additionally suppressed to levels less than -35 decibels through the use of strategically placed diffraction fences. Design values for the dimensions and locations of such fences can be calculated using Fresnel zone theory*, while final adjustments to the fence installations must be accomplished experimentally by means such as probe data of the field over the test aperture. While general criteria have not been developed which apply to all elevated range configurations, experience has shown that fences which screen approximately the first 20 Fresnel zones on the mean range surface will provide from -35 decibels to -40 decibels of suppression of range surface reflections when the terrain is nominally regular in cross-section and the previously discussed criteria are satisfied. It is necessary to arrange these fences so that little or no blockage of the main lobe of the transmitter pattern is caused by the fences. This precaution ensures that the residual variations in the field over the test aperture due to diffraction effects at the fences will represent a reasonable compromise with the level of reflected signal suppression.

*Although Fresnel zones are rigorously defined on the basis of point source radiators, for practical antenna range geometries Fresnel zones for a point in the receiving aperture can be defined by regarding the transmitting antenna to be a point source located at the center-of-phase of its aperture.

A full development of Fresnel zone theory will not be presented here. The pertinent parameters of the Fresnel zones over a mean planar surface are the center, length, and width of the ellipse which describe the outer bound of a particular zone. These parameters can be calculated from the range geometry and the frequency of operation.*

In addition to providing line-of-sight clearance, low-level range surface illumination, and range surface screening via diffraction fences, the facility design should also ensure the clearance of all major extraneous reflecting or diffracting obstacles over the region within about 1.5 to 2 times the azimuthal main-lobe width of the transmitted pattern. Grading along the range boundaries can be performed to remove regions of possible wide-anglespecular reflection into the test aperture.

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* See, for example, Hollis, J. S., et al, Microwave Antenna Measurements, Section 14.2.4.

A2.3.1 Effects of Reflected Energy

Consider the case of a direct-path plane wave of amplitude E_d which is normally incident on the test aperture[12] as shown in Figure A2.11(a). Let an extraneous plane wave of amplitude E_r enter the aperture at an angle θ from the normal. At any given time, t, the phase of the direct wave is constant across the aperture and the direct-path field magnitude may be expressed in phasor notation as

$$E_d^* = E_d e^{j(\phi+\omega t)} \qquad (4.1)$$

where the asterisk denotes a complex quantity.

The phase of the postulated extraneous plane wave will vary across the aperture, so that the extraneous field magnitude is given by

$$E_r^* = E_r e^{j(2\pi x \sin\theta/\lambda + \phi' + \omega t)} \qquad (4.2)$$

In (4.1) and (4.2), ϕ and ϕ' are constants, λ is the wavelength, and x is distance measured across the aperture parallel to the plane containing the directions of propagation of E_d^* and E_r^*. The magnitude of the total field in the aperture is that given by[13]

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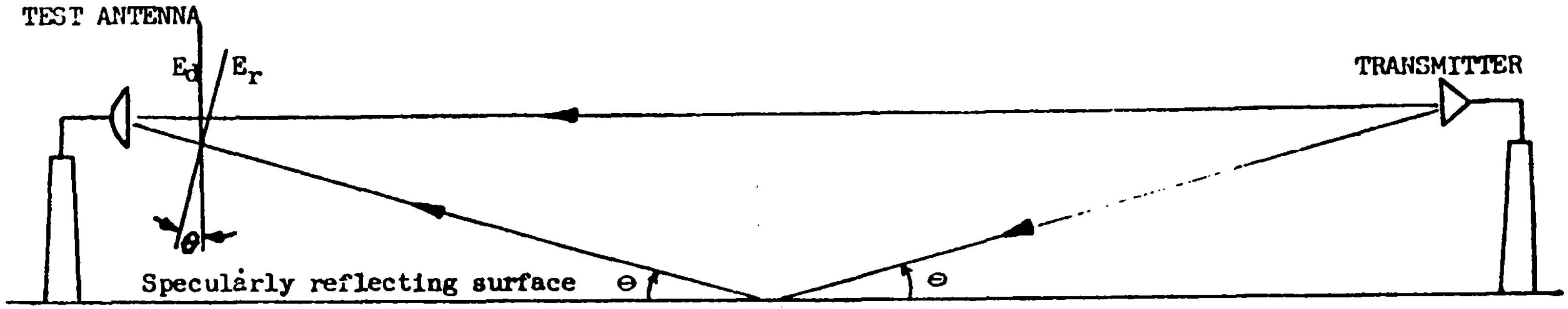
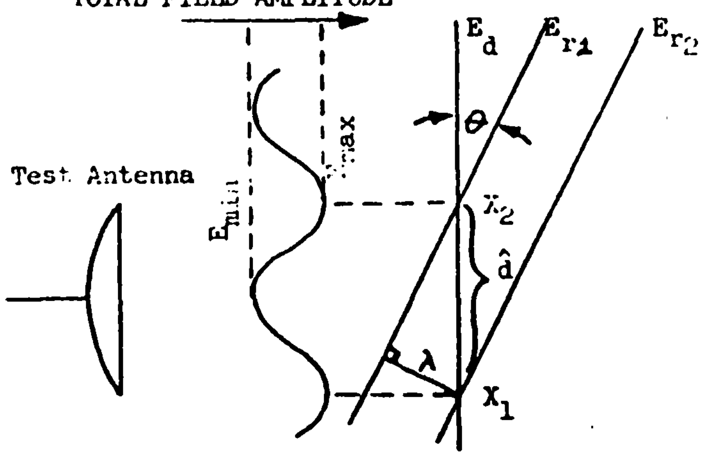
[12]The discussion here assumes a separation, R, between source and receiving antennas equal to or greater than $2D^2/\lambda$, where D is the maximum dimension of the receiving aperture. It is further assumed that the ratio D/R is small in comparison with the half-power beamwidth of the source antenna's pattern, so that the plane wave approximations are meaningful.

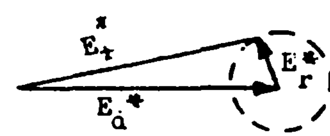
[13]This simplified example assumes that the polarizations of the reflected and direct-path waves are identical. While this is not strictly true, often the reflected wave will contain a large component with polarization identical to that of the direct-path wave.



(a) Reflected Wave Incident on a test aperture at an angle θ from the direction of propagation of the direct wave.



(b) Details of wave interference.



(c) Equivalent Phasor Representation.

Figure A2.11 Simplified sketch illustrating total aperture field variation caused by a single specularly reflected wave.

$$E_t^* = E_d^* + E_r^* = \left[E_d e^{j\delta} + E_r e^{j(2\pi x \sin\theta/\lambda + \delta')}\right] e^{j\omega t} \quad (4.3)$$

Equation (4.3) describes a field with a sinusoidal variation in one dimension as sketched in Figure A2.11(b). In this figure, E_{r1} and E_{r2} represent two successive wavefronts of the reflected wave separated by λ, and E_d is a wavefront of the direct wave of identical phase. At points x_1 and x_2, the resultant amplitude is

$$E_{max} = E_d + E_r \quad (4.4)$$

Halfway between these two points the waves are in phase opposition, and the resultant amplitude is

$$E_{min} = E_d - E_r \quad (4.5)$$

The maximum amplitude variation within the aperture is thus given by

$$E = E_{max} - E_{min} = 2E_r \quad (4.6)$$

Figure A2.12 is a graph of the magnitude of the resultant field amplitude ripple as a function of the ratio E_r/E_d.

The angle θ can be determined by

$$\theta = \sin^{-1}(\lambda/\hat{d}) \quad (4.7)$$

where $\hat{d}$ is seen in Figure A2.11(b) to be the spatial period of the resulting interference pattern across the aperture.

The field in the aperture may also be represented as the sum of the two phasors, E_d^* and E_r^*, as illustrated in Figure A2.11(c), where E_r^* rotates relative to E_d^*. The phase of the field across the aperture will vary as the phase of the resultant of the direct-path and reflected phasors. The maximum phase variation for this plane wave case is then

$$\Delta\phi = 2 \sin^{-1} (E_r/E_d), \quad (4.8)$$

where E_r is less than E_d.

The preceding example, although representing an idealized reflection, demonstrates the manner in which extraneous signals distort an otherwise planar wavefront. In a practical test situation, neither the direct nor the extraneous waves would be strictly planar, and there would be extraneous signal sources which could contribute to distortion of the incident field. For elevated ranges, however, for which the region around the range line-of-sight is relatively clear of reflecting objects, the primary source of extraneous signals is the range surface and the mathematical model developed above is a useful approximation to the physical situation.

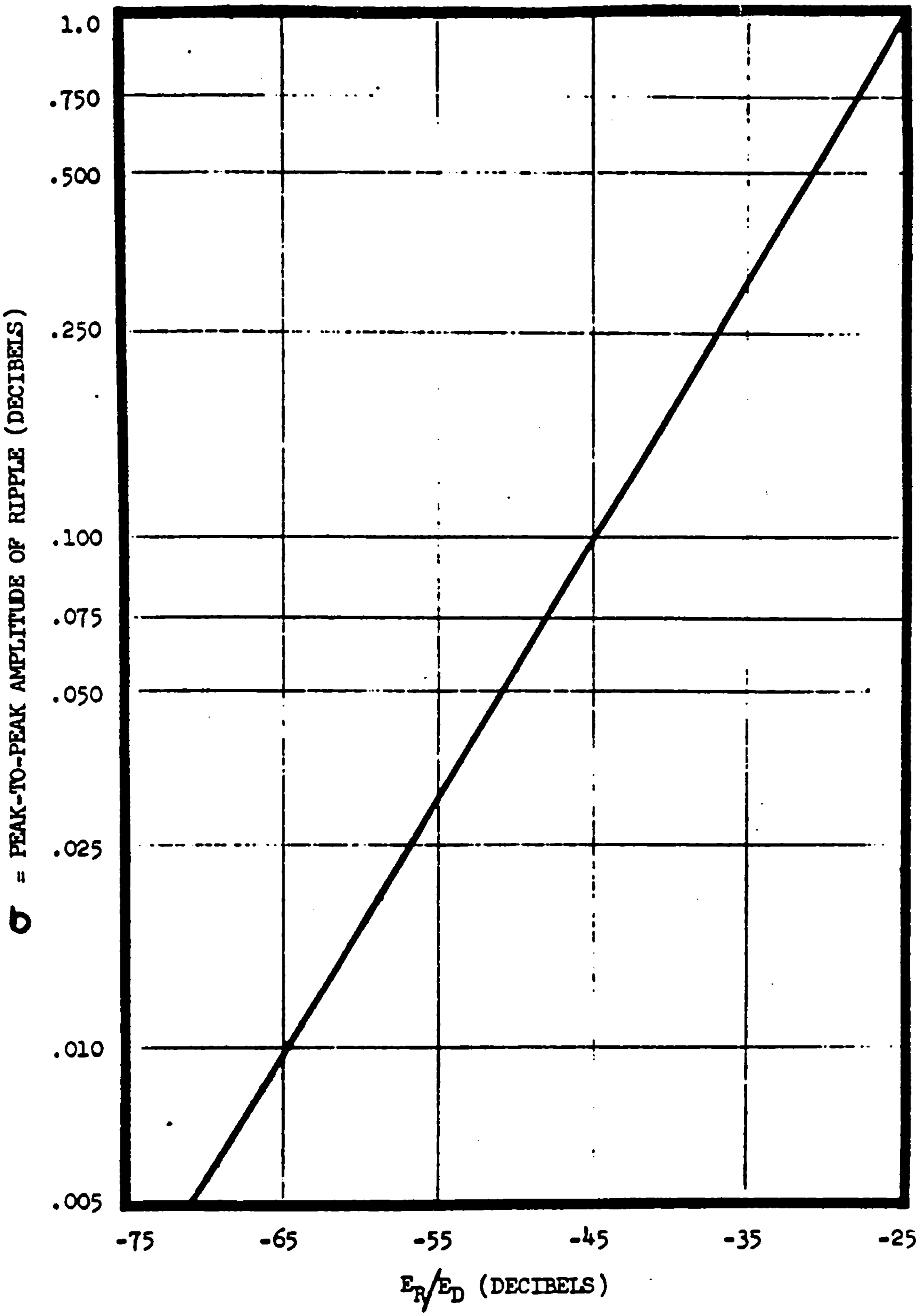


Figure A2.12 Magnitude of the maximum field perturbation as a function of the relative magnitude of the reflected signal.

A2.3.2 Range Fences 14

Energy which is incident on the range surface is reradiated in all directions; that energy which is reflected into the test aperture is a summation of wavelets reradiated from every point on the surface. If the surface is smooth in terms of the wavelength of the radiation, the energy striking the surface will be reradiated with a major lobe in the specular direction (angle of incidence equal to the angle of reflection) in accordance with Fermat's principle of stationary phase[15]. When the wavelength is sufficiently short and the range separation sufficiently long, reflection from a smooth range surface approaches the geometrical optics approximation in which all energy is reflected in the specular direction.

Reflection from a smooth surface can be analyzed by defining Fresnel zones on the surface similar to those defined in physical optics[16]. If the surface is planar, as well as smooth, the Fresnel zones produced by a point source radiator will be defined by a family of expanding ellipses[17]. Conventionally the zones are identified by numbering them consecutively, beginning with the inner zone. The specular point falls within the first Fresnel zone and, for typical elevated ranges, is near the geometrical center of the first zone. Although reflected energy from the entire

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[14]For further discussion of this topic see:
T. J. Lyon, et al, "Evaluation of the NASA-KSC-MILA RF Boresight Test Facility at X-Band and S-Band," FINAL REPORT Contract No. NAS10-2103, Scientific-Atlanta, Inc., N-67-13025.
J. S. Hollis, et al, "Investigation of Precision Antenna Pattern Recording and Display Techniques, Phase II," FINAL REPORT, Contract No. AF30(602)-3425, Scientific-Atlanta, Inc., AD630214.

[15]S. Silver, Microwave Antenna Theory and Design, Radiation Laboratory Series, Vol. 12, McGraw-Hill Book Co., pp. 119-128, 1950.

[16]See, for example, D. E. Kerr, Propagation of Short Radio Waves, Radiation Laboratory Series, Vol. 13, McGraw-Hill, pp. 411-418, 1951.

[17]It should be noted that Fresnel zones, as used here, are defined in terms of isotropic radiators and receivers. Such zones differ considerably from the half-period zones which could be defined in terms of the actual directive source and test antennas. Excellent results have been achieved on the basis of isotropic antenna analysis, however, and further complication of the mathematics appears to be unnecessary in most cases.

range surface contributes to the extraneous signal level at the test aperture, the level can be reduced considerably by blocking reflected energy from the first several Fresnel zones. Reduction of the relative extraneous signal level at the test aperture by approximately 10 to 20 decibels is achievable by blocking reflections from at least the first 20 zones, for typical elevated antenna range problems[18]. This blockage is easily achieved through the use of conducting fences placed on the range surface over the central Fresnel zones[19].

In choosing a fence configuration for an elevated range, consideration must be given to the problem of interference due to diffraction over the fence edges. The energy which reaches the test aperture is the summation of contributions from all points on a spherical wavefront encompassing the source, as described in Huygen's principle[20, 21, 22]. Thus, blockage of any portion of the transmitted wavefront results, through the process of diffraction, in a perturbation of the energy incident on the test aperture. The nature of the diffraction disturbance can be illustrated with the simplified example of diffraction over an infinite, straight, absorbing edge which is placed between a radiator and a plane AB, as shown in Figure A2.13. It is desired to know the magnitude of the field at a point P, which lies in the plane AB. The absorbing half-plane blocks a portion of the wavefront; the field at P is determined by applying Huygen's principle to sum the contributions at P from the remainder of the wavefront. The normalized field at P can be approximated by[23]

$$\frac{E}{E_0} = \left| \frac{1}{\sqrt{2}} \int_{v_0}^{\infty} e^{-j(\pi v^2/2)}\, dv \right|, \qquad (4.9)$$

$$v = u \left[\frac{2(d_1 + d_2)}{\lambda d_1 \; d_2} \right]^{\frac{1}{2}} \qquad (4.10)$$

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[18] Lyon, et al, op cit.

[19] Ideally, absorbing fences are preferred to eliminate the possibility of reflections from the fences resulting in measurement interference; if the fences are properly designed, however, interference from this source is often negligible.

[20] E. C. Jordan, Electromagnetic Waves and Radiating Systems, Prentice-Hall pp. 572-577, 1950.

[21] Bruno Rossi, Optics, Addison-Wesley, Chapter 4, 1957.

[22] R. S. Longhurst, Geometrical and Physical Optics, Chapter 10, 1957.

[23] E. C. Jordan, op cit.

and where E_0 is the field which would result from the unobstructed wave, u is the arc length measured along the wavefront from the line TP, v_0 corresponds to the point of the wavefront which inter - sects the top of the obstruction, d_1 is the radius of the wavefront, and d_2 is the distance from the wavefront to P.

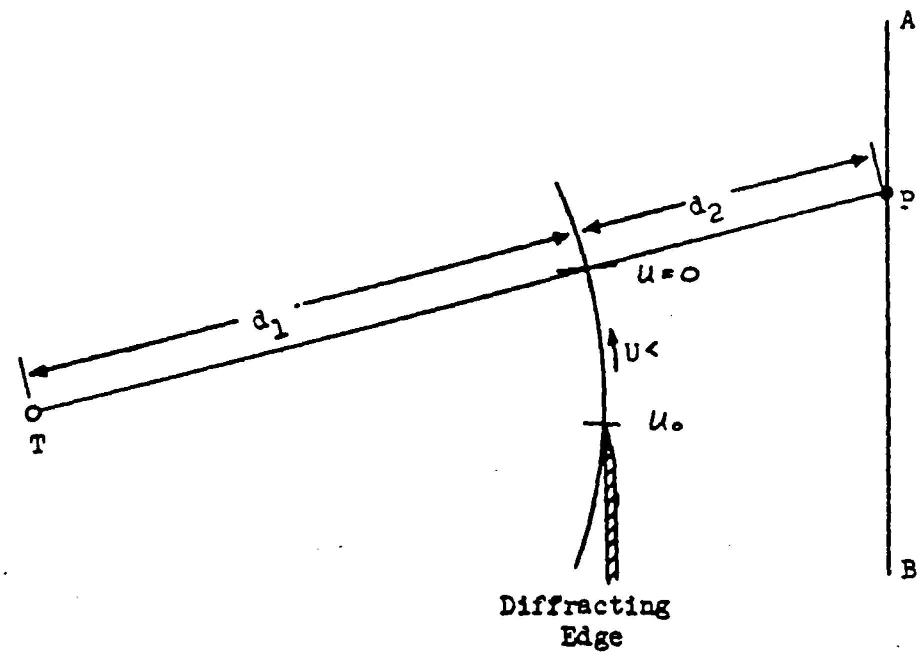

Figure A2.13 Edge Diffraction Geometry.

A plot of equation (4.9) is reproduced in Figure A2.14. Positive values of v_0 correspond to field points in the shadow region; negative values correspond to field points in the region of direct illumination. The resultant field magnitude in the direct illumination region varies in an oscillatory manner with the location of the observation point. This disturbance is essentially equivalent to that which would be caused by a coherent cylindrical wavefront emanating from the diffracting edge which systematically interferes with the spherical wavefront of the unobstructed signal.

The foregoing example is obviously idealized. Clearly, an infinite, perfectly-absorbing half-plane is not physically realizable; it has been shown, however, that diffraction patterns for finite, reflecting edges are similar to the theoretical pattern of Figure A2.14. [24, 25].

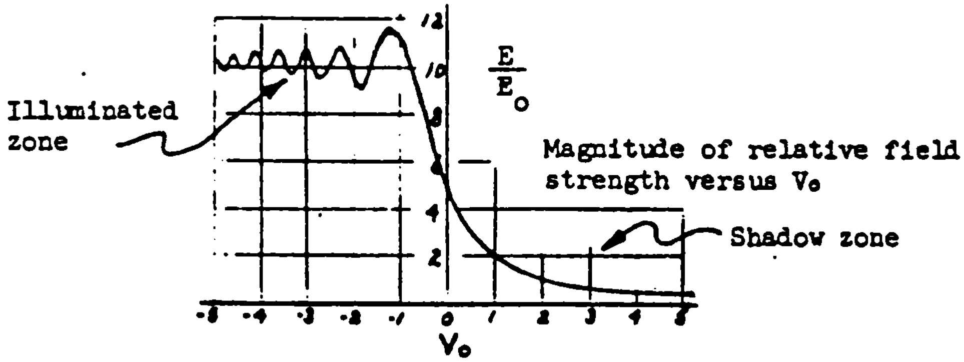

Figure A2.14 Field amplitude due to diffraction at an edge.

Diffraction disturbances can be reduced by increasing the clearance of the range line-of-sight above the fences and by utilizing the directivity of the source antenna to minimize the energy blocked by the fences. A desirable design goal is to provide for sufficient clearance over each fence to allow passage of the entire principal lobe of the radiated energy distribution. Further reduction can be achieved, if required, by shaping the tops of the fences (with serrations, for example) to destroy the phase coherence of the diffracted energy.

[24] H. Martinides, "The Screening Effect of Obstacles With a Straight Edge," Goddard Space Flight Center, N65-33504-04, 1965, p.5.

[25] T. J. Lyon, et al, op cit.

A2.4 Probe Data Requirements

Paragraph 4.7 establishes requirements for the electromagnetic performance of the test range(s) used by the Contractor to verify the electrical characteristics of the antennas. The electromagnetic performance of the test range(s) will be verified by recording the probe data described below and reporting these results in the Contractor's range validation report. The probe data must meet the requirements established below prior to acceptance of the range(s) as suitable for the testing required by this contract.

A probe mechanism similar to that shown in Figure A2.15 shall be used for the field measurements required below. The 3-dB elevation and azimuth beamwidths of probe shall be no less than 30 degrees. The elevation beamwidth of the probe shall not be less than 2 $\tan^{-1}(4h_t/Ro)$ radians where h_t and Ro are defined in Figure A2.10.

All probe data and related requirements described below are necessary at both 1030 MHz and 1090 MHz.

A2.4.1 Probe Measurements Over Test Aperture

The plane normal to the line of sight from the source antenna to the test antenna and passing thru the geometrical center of the test antenna aperture when this aperture is also normal to the line of sight is the test aperture plane. The test aperture is the minimum region within the test aperture plane that includes all projections(parallel to the above mentioned line of sight) of the test antenna aperture over all angles of elevation tilt and azimuth rotation employed during antenna testing.

The following probe data and associated performance are required.

(1) With the source antenna oriented to transmit vertically polarized energy and the field probe antenna oriented to receive vertically polarized energy along the line of sight to the source antenna, record the detected signal from the probe antenna as it is moved across the horizontal center line of the test aperture. Repeat this recording with the probe moving along both diagonals across the test aperture (through the center of the test aperture) and along the entire vertical center line of the test aperture.

(a)The amplitude taper, for any recording across the entire test aperture, shall be less than 0.25 dB as determined by measuring the difference between the amplitudes of the maximum and minimum points of the taper.

(b)The amplitude taper shall be centered on the test aperture in the sense that the peak of the taper shall be centered on the test aperture and, for any one recording, the taper levels at the edges of the test aperture shall be the same to within 0.10 dB.

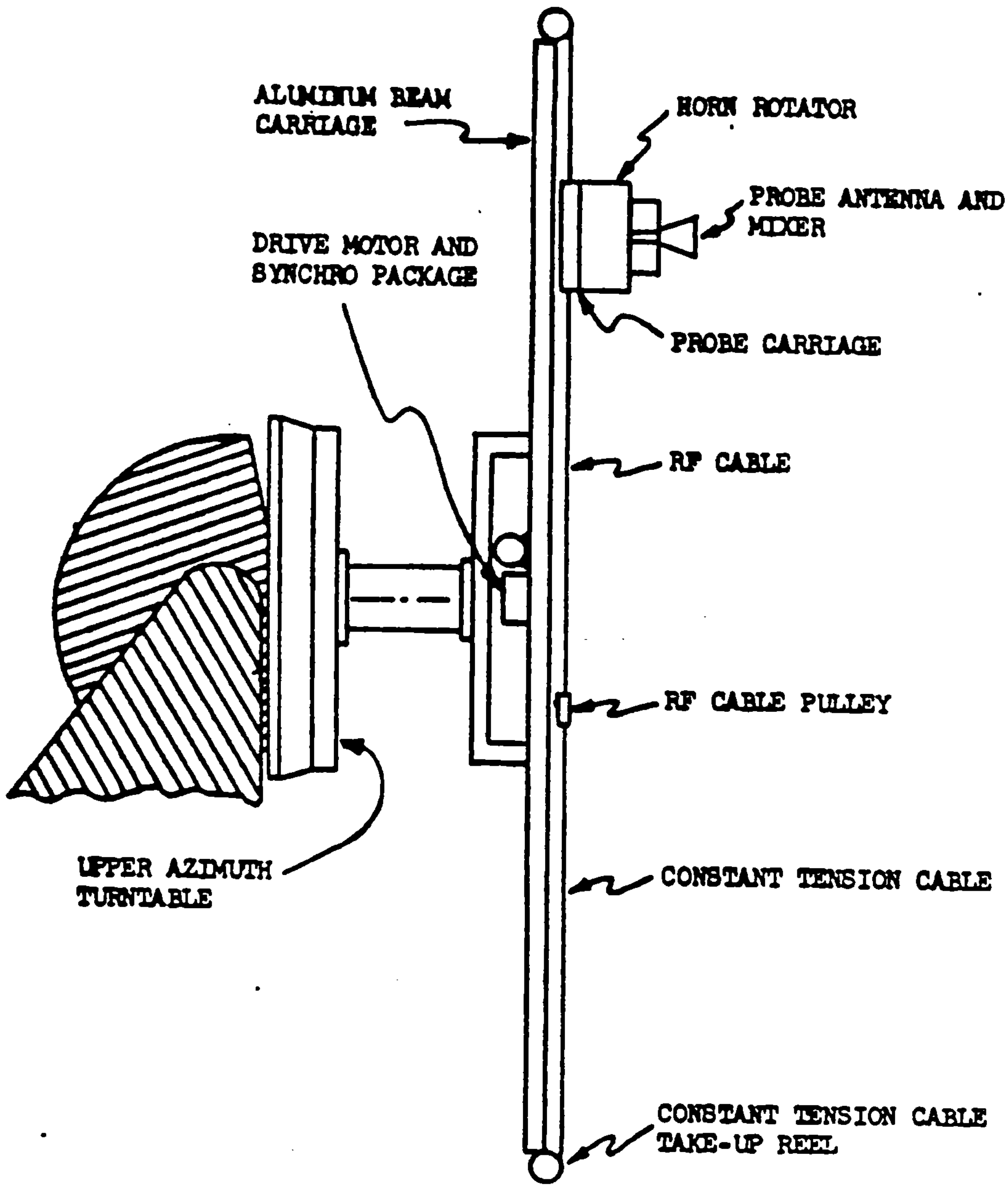

Figure A2.15 Schematic diagram of field probe mechanism.

(c) The maximum peak-to-valley variation between any maximum and the adjacent minimum shall be less than 0.35 dB when the effects of taper have been accounted for.

(d) The maximum peak-to-valley excursion of any recording across the entire test aperture shall be less than 0.65 dB.

(2) Repeat the recordings of (1) above with the source and probe antennas oriented for horizontally polarized energy. These data shall meet the requirements of (1a) through (1d) above.

(3) With the source antenna oriented to transmit vertically polarized energy and the field probe oriented to receive horizontally polarized energy, record the detected signal of the probe antenna as it is moved across the test aperture along the horizontal center line. Reorient the probe antenna to receive vertically polarized energy and insert 35 dB attenuation in the path of the detected signal. Record the attenuated probe signal as the probe is moved across the test aperture along the horizontal center line such that the received signal strength for a given probe position appears directly above the cross-polarized level previously recorded. The signal level in the first case shall not exceed the signal level recorded for the later case. Repeat the recordings with the probe moved along both diagonals and the vertical center line across the entire test aperture. For all recordings, the horizontally polarized signal level shall not exceed the level of the attenuated vertically polarized signal.

(4) Repeat the recordings of (3) above with the source antenna oriented to transmit horizontally polarized energy and the probe antenna oriented for alternately recording the vertically polarized signal and the attenuated horizontally polarized signal. For all recordings, the vertically polarized signal level shall not exceed the level of the attenuated horizontally polarized signal.

A2.4.2 Probe Measurement Over 360 Degrees Azimuth

(1) Orient the source antenna to transmit vertically polarized energy and rotate the probe carriage mount so that the axis of rotation of the carriage is vertical. Face the probe antenna toward the source and orient the probe to receive vertically polarized energy. Position the probe carriage vertically so that it is within the test aperture. Move the probe antenna horizontally on the field probe mechanism to a point approximately 5 wavelengths out from the axis of rotation. Rotate the probe carriage 360 degrees in azimuth and record the detected signal. Move the probe antenna approximately one wavelength horizontally inward toward the axis of rotation. Rotate the probe carriage 360 dgrees in a manner that overlays the same azimuth angles precisely over those previously recorded. Continue this procedure moving the probe antenna in approximately one wavelength steps each time until it has been moved horizontally to the opposite side of the axis of rotation by approximately

five wavelengths. The overlayed patterns are those of the probe antenna taken at various horizontal positions each side of the axis of mount rotation. The amplitude variation of these patterns at each angle of rotation is an indication of thereflected energy. The actual pattern of the probe antenna is the mid-power position of the overlayed patterns. The relative reflected power arriving from the azimuth θ shall be estimated as:

$$\frac{E_r}{E_d}(\theta) = 20 \log_{10} \frac{10^{\sigma/20} - 1}{10^{\sigma/20} + 1} + G(\theta) \quad dB$$

Where σ is the measured maximum-to-minimum amplitude variation (in dB) at the angle θ and $G(\theta)$ is the gain (in dB) of the probe antenna (with respect to the peak of the probe pattern) at the azimuth angle θ. At all azimuth angles $0^\circ \leq \theta < 360^\circ$, the estimated relative reflected power shall be less than -35 dB.

(2) Orient the source and probe antenna for horizontally polarized energy and repeat the measurements and associated computations of (1) above. At all azimuth angles, $0^\circ \leq \theta \leq 360^\circ$, the estimated relative reflected power shall be less than -35 dB.

(3) With the source antenna oriented to transmit vertically polarized energy and the probe antenna oriented to receive horizontally polarized energy, position the probe carriage as in (1) above and move the probe horizontally to a distance of at least five feet from the axis of rotation. Rotate the probe carriage 360 degrees in azimuth and record the detected signal. Reorient the probe antenna to receive vertically polarized energy and insert 35 dB attenuation in the path of the detected signal. Record the attenuated signal of the probe antenna at the peak of the beam. The signal recorded in the first case over the complete 360 degrees shall not exceed the signal level recorded for the later case., This test measures cross polarization throughout 360 degrees of azimuth that can affect the accuracy of the cross polarization measurement of the test antenna.

(4) Repeat the measurement of (3) above with the source antenna oriented to transmit horizontally polarized energy and the probe antenna oriented first for vertically polarized energy (record probe signal over 360° azimuth) and then for horizontally polarized energy (record attenuated probe signal at the peak of the probe beam). The vertically polarized signal shall not exceed the attenuated horizontally polarized signal level over 360 degrees in azimuth.